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JULY 2014

NATIONAL GEOGRAPHIC

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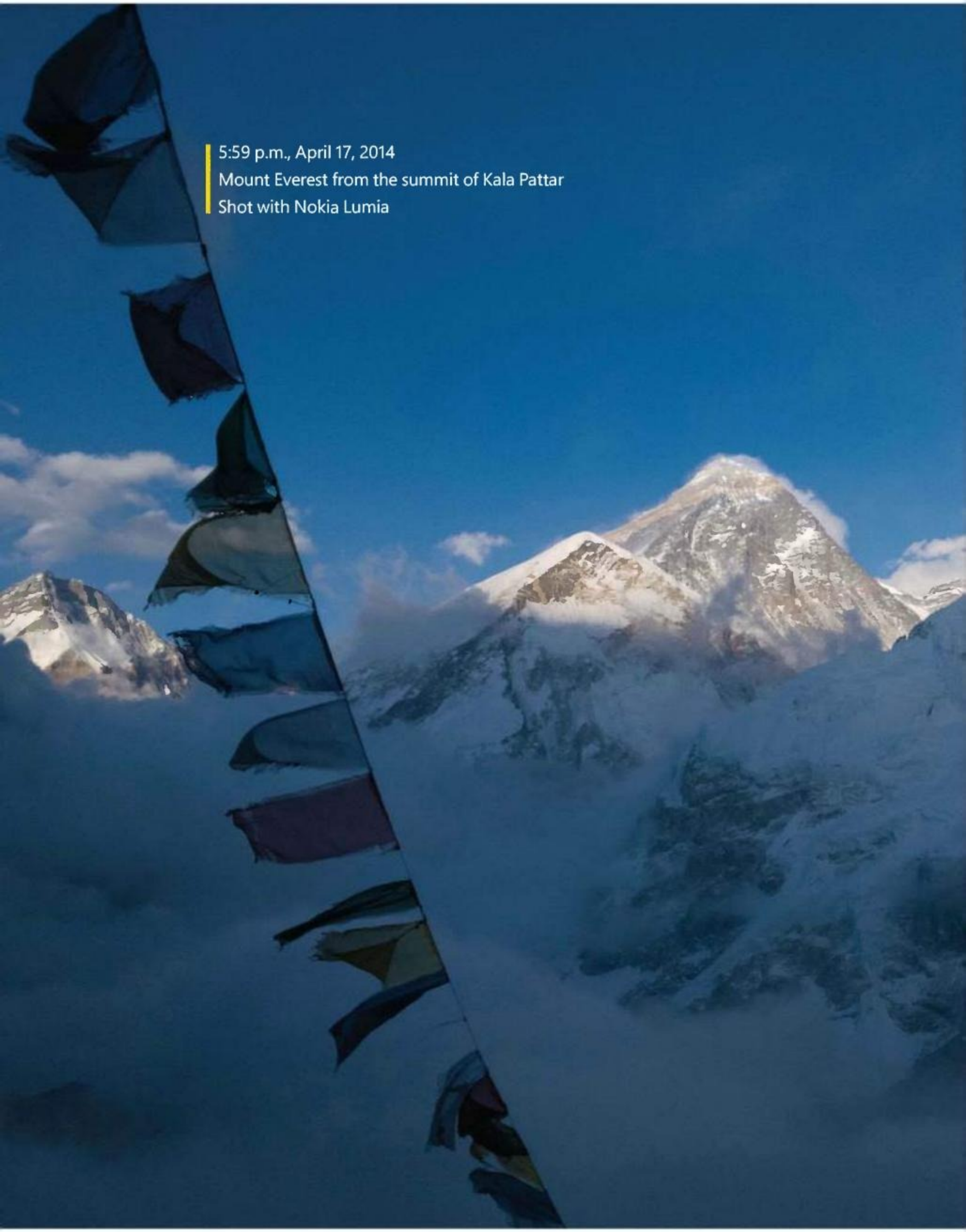
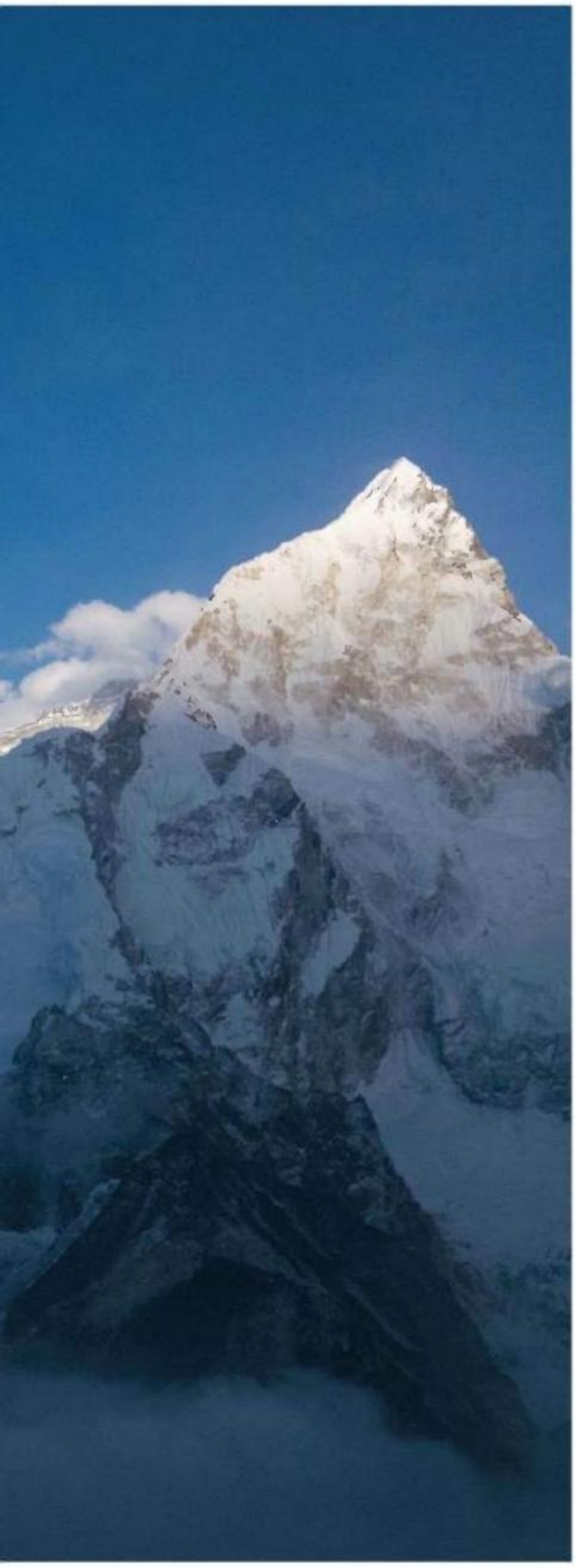
LIFE BEYOND EARTH


5:59 p.m., April 17, 2014
Mount Everest from the summit of Kala Pattar
Shot with Nokia Lumia



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"This expedition was the biggest challenge yet in my assignment to capture the Seven Natural Wonders of the World. The draw of Mount Everest is unlike anything else, it not only holds amazing majesty and history, but also danger.

"We followed the same path that so many courageous, intrepid explorers have trekked for decades; capturing the entire journey with Nokia 20 MP Pureview technology. The fierce force of nature was ever-present—from dawn's first light to the moment the setting sun vanished, we were surrounded by harsh wind, cold, rock, ice, and snow. It was a humbling experience. Standing in Everest's shadow filled me with ultimate respect for all those who have braved its unrelenting power. What a privilege to walk in their footsteps."

—Stephen Alvarez, National Geographic photographer

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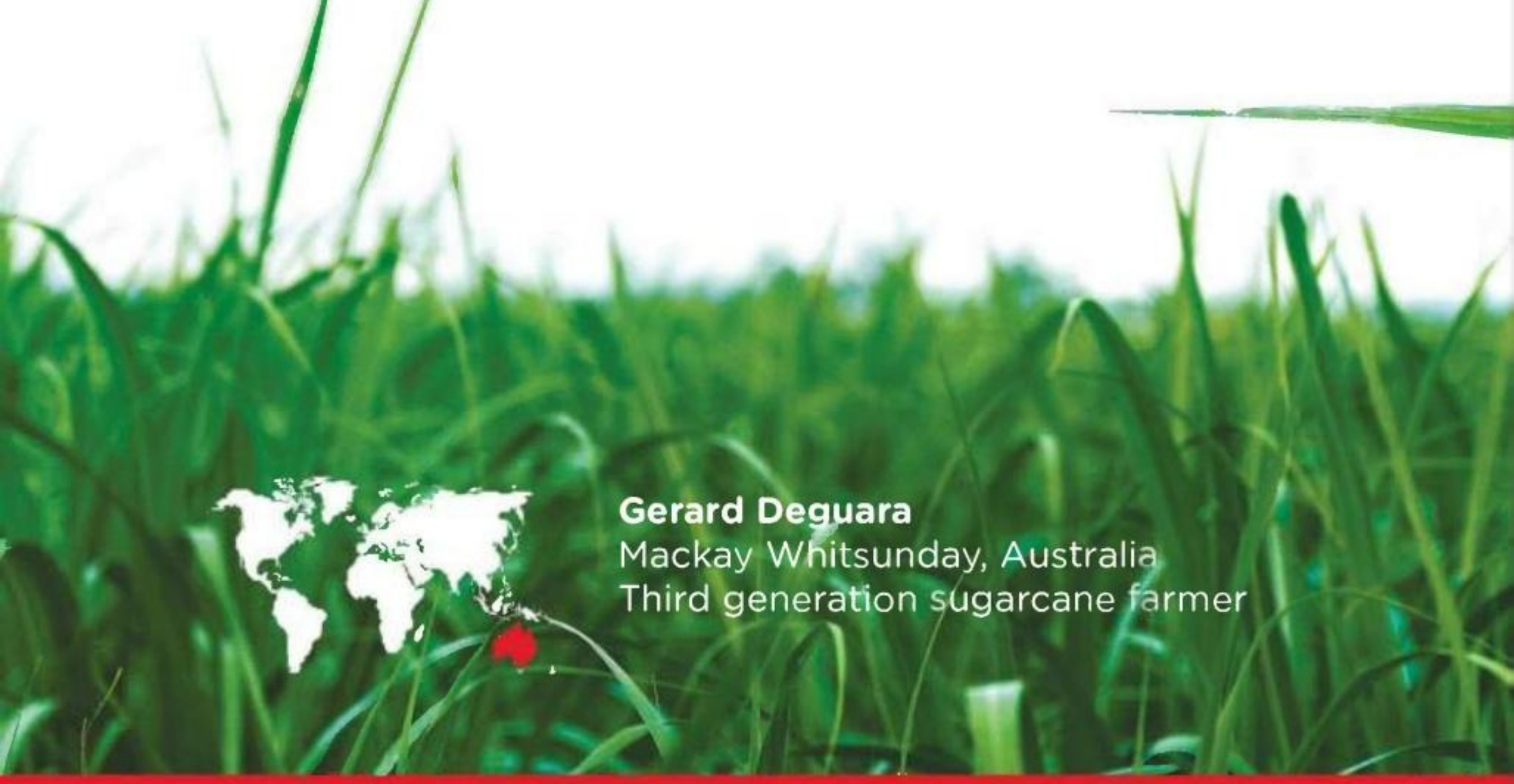

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VOL. 226 • NO. 1

NATIONAL GEOGRAPHIC

We are all pilgrims in the Hejaz. Wanderers through time.
page 101

Karst peaks rise like ghosts at Yangshuo in China's Yulong River Valley.

CARSTEN PETER

July 2014

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One of the oldest questions may be answered in our lifetimes: Are we alone?
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OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY

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Tiny turbines may someday power your cell phone.

Mangroves on the Move
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Found

On the Cover Jupiter's moon Europa (foreground) may harbor life in the liquid ocean beneath its icy surface—fueled in part by elements from its sister moon Io. *Art by Dana Berry*

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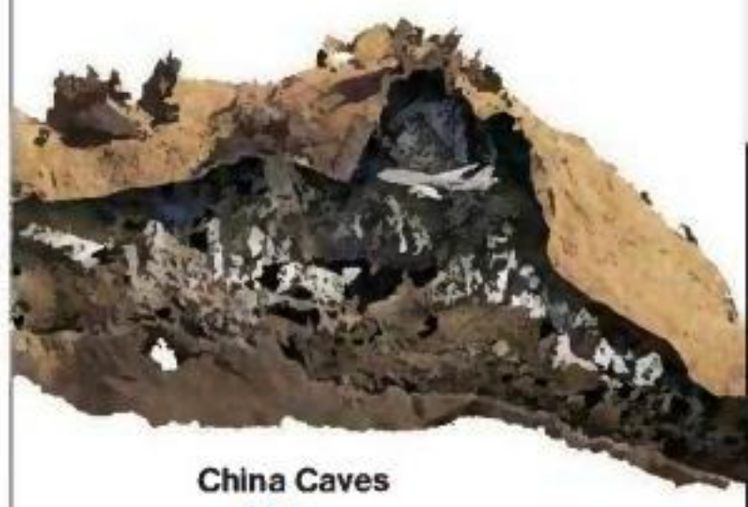
Interactive
Could there be life on Europa?



China Caves
Video
Fly through the karst and caves.

Hejaz
Video
Follow Paul Salopek as he walks around the world.

PHOTOS: REBECCA HALE, NGM STAFF (CUFF); MOHAMAD BANOUNAH (HEJAZ)

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Meet Our New Editor in Chief

As Chris Johns takes on a new role as the National Geographic Society's chief content officer, Susan Goldberg, the magazine's former executive editor for news and features, becomes the 126-year-old publication's tenth editor in chief—and the first woman to hold that position. We asked them both a few questions:

Chris, what makes you proudest about your nine years as editor in chief? And Susan, what do you most look forward to as you take on the job?

Chris Johns: I'm proud that we've been able to increase public awareness of important issues. We've been influential in helping the world deal with the illegal wildlife and ivory trades, climate change, child brides and other human rights issues. We've brought these global issues right into people's living rooms.

Susan Goldberg: I've been chasing the news for 35 years, and now I have the opportunity to get in front of it. The topics that are central to National Geographic's coverage—the environment, climate change, cultures, innovation, and science—also are central to the national conversation about the future. We're expert storytellers in all these areas, and it's hard to imagine a more important, relevant, or newsier place to be for a magazine and digital news source.

What do you both see for the future of National Geographic?

CJ: I'm looking forward to new and innovative ways to tell stories. The methods of delivering information are getting better all the time. I've always wanted our stories to resonate long after publication, and now, because of the great tools we have, there are unparalleled opportunities to get the great issues of our day out and keep those conversations going.

SG: We have the ability to reach a larger and more diverse group of readers than we've ever had. And we will do that in the print magazine, but we must become equally well known for our work across other platforms—digital, mobile, video—with timely and lively news and information. Now we can cover what people are talking about in the moment with uniquely powerful visual and textual storytelling.

Chris, do you have any advice for Susan in her new position?

CJ: Embrace change. There's a lot happening right now at National Geographic, and throughout the world of media. I don't think there's a better time to be an editor of a magazine.

SG: I agree!

PHOTO: REBECCA HALE, NGM STAFF

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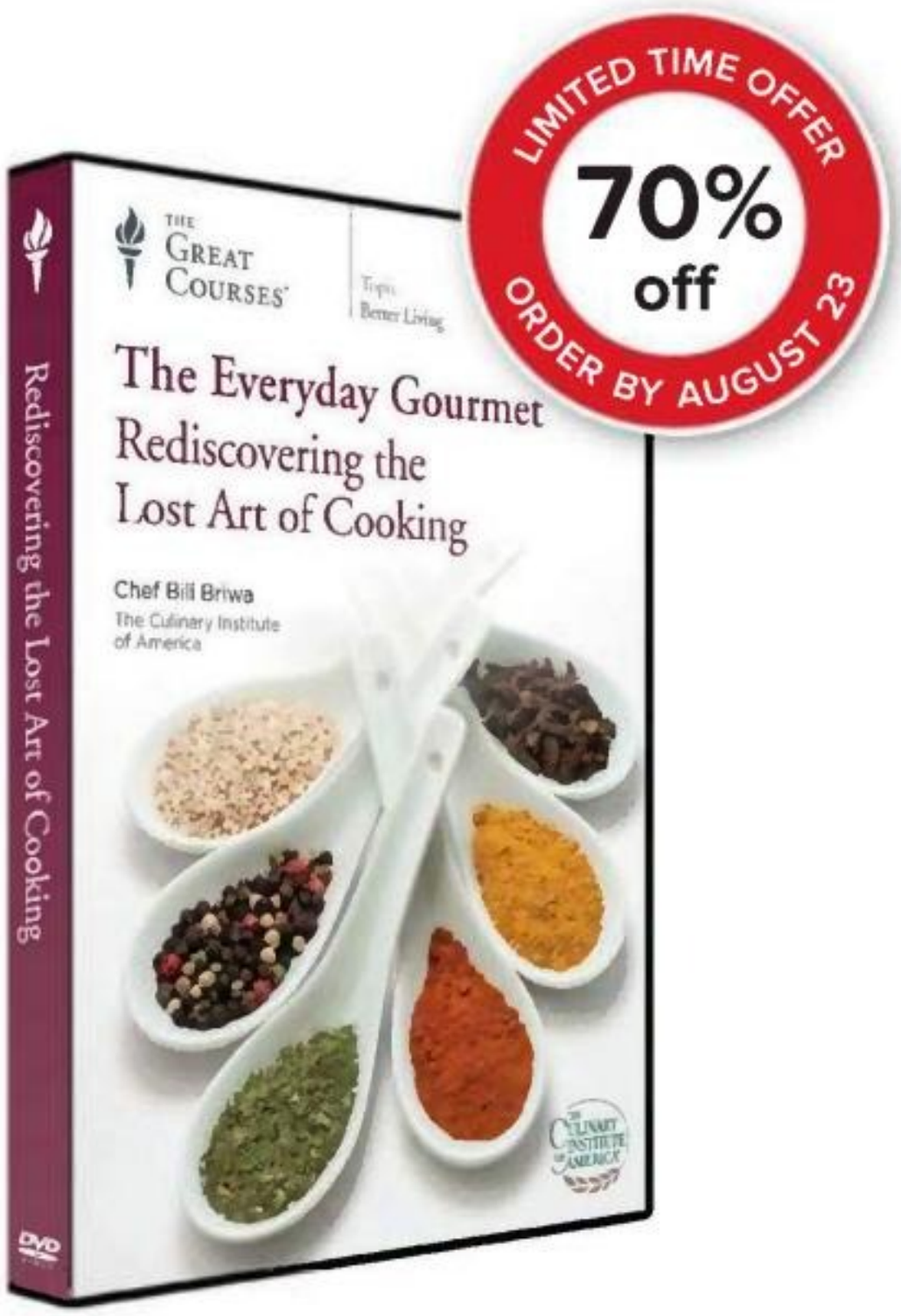

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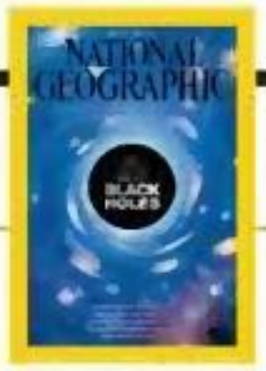

Damascus: Will the Walls Fall?

I found a sad irony in your issue featuring the dystopian situation in Syria and the cosmic scale of black holes. Syria's plight reflects the cruel reality at the heart of civilization. The toxic combination of religious and ethnic hatred, the inability to attain a civil society, and the failure to accept the primacy of science will lead to the creeping destruction of a culture that stretches to antiquity. On the other hand we are drawn to a dark specter of unimaginable power and distance until we fall into the final singularity. It makes our human condition, no matter how grand or pathetic, seem trivial.

MICHAEL MAFFETT
Lake Burton, Georgia

Author Anne Barnard asserts of Syrian Jews that "most left after the founding of Israel, when the government began viewing them with suspicion." For centuries Jews and other non-Muslims in Syria were restricted in their movement and employment and were subjected to a special tax called the jizya. In the 1940s mobs rampaged through the Jewish quarters. Jews who could flee to Israel after 1948 did.

DORON LUBINSKY
Atlanta, Georgia

Star-Eater

The article on black holes reinvigorated my interest in the cosmos—fully blowing my mind with the multiverse theory. The idea that our universe sprang from a singularity and continues to give birth to others in a similar manner is enchanting and mesmerizing. Thank you for making me feel 13 years old—when I read Arthur C. Clarke for the first time—all over again.

ZACHARIAH L. SEVILLE
Ottawa, Ontario

Michael Finkel's article was thought provoking. However, as a Christian, I felt that some of his ideas left me hanging. In the section about black holes being "basically time machines," he writes "it's possible that to give birth to a new universe you first need to take a bunch of matter from an existing universe, crunch it down, and seal it off." For a mere "you" to do this of course would be impossible, but if the name of God, our Divine Creator, were entered into the article at this point, science makes sense! The Bible does not contradict science but clarifies it.

DOTTIE GRANGER
Camano Island, Washington

Corrections/Clarifications

MARCH 2014, WHERE GREENSTONE GROWS
Page 59: A new elevation of Aoraki/Mount Cook was announced after we went to press. The new figure is 12,218 feet (3,724 meters).

OUICKSILVER Pages 69 and 82: Photo captions incorrectly say tuna were caught in the Mediterranean. They were caught in the Atlantic. Page 72: Iron Age fishermen would have been Anatolian, not Turkish.

PEOPLE OF THE HORSE Page 113: Relay riders must transfer horses two, not three, times.

FEEDBACK *Readers responded to our story on black holes.*

ART: LAWSON PARKER, NGM STAFF

EMAIL comments to ngsforum@ngm.com; for subscription help, ngsline@customersvc.com

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WRITE National Geographic Magazine, PO Box 98199, Washington, DC 20090-8199. Letters may be edited for clarity and length.

I never feel more insignificant than when reading about black holes.

I might suggest a slightly different title for your March cover story, "The Latest Truth About Black Holes."

My view of our world morphed as I read.

Each time humanity thinks it has an answer to what makes our universe tick, 20 other questions pop up.

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FINANCE: Michael Ulica
DEVELOPMENT: Bill Warren
SUSTAINABILITY: Hans H. Wegner
TECHNOLOGY: Jonathan Young

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VISIONS

Brazil
As a fast-moving storm engulfs Pedra da Gávea mountain, Caio Afeto seems to walk on clouds. The professional highliner was traversing two cliffs above Rio de Janeiro when a coastal front blew in, hiding the half-mile-high summit in mist.

PHOTO: KEITH LADZINSKI

Russia
Snared by a brown bear, a sockeye salmon spills a string of orange roe into Kuril Lake. Around a million of these fish swim from the Pacific Ocean to the Kamchatka Peninsula each summer to spawn—a boon to bears fattening up for winter hibernation.

PHOTO: VALTER BERNARDESCHI

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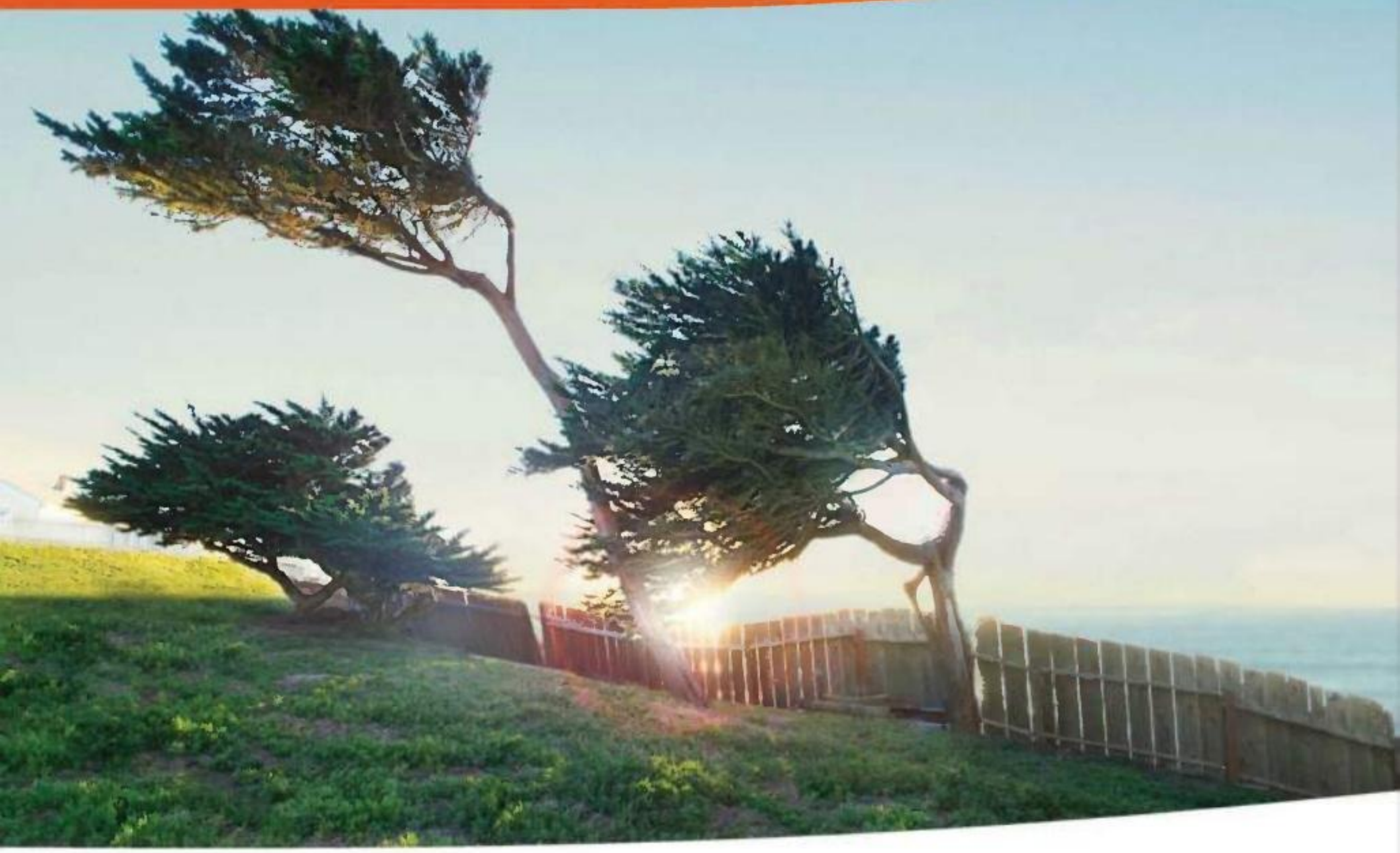
Papua New Guinea
In Milne Bay schools of fish swirl around the coral-encrusted piles of a crumbling wharf. The warm waters—part of the biologically rich Coral Triangle marine area—are home to thousands of fish species.

PHOTO: JULIAN COHEN

For people with a higher risk of stroke due to
Atrial Fibrillation (AFib) not caused by a heart valve problem



ELIQUIS® (apixaban) is a prescription medicine used to reduce the risk of stroke and blood clots in people who have atrial fibrillation, a type of irregular heartbeat, not caused by a heart valve problem.

IMPORTANT SAFETY INFORMATION:

- **Do not stop taking ELIQUIS for atrial fibrillation without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke.** ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.
- **ELIQUIS can cause bleeding, which can be serious,** and rarely may lead to death.
- **You may have a higher risk of bleeding if you take ELIQUIS and** take other medicines that increase your risk of bleeding, such as aspirin, NSAIDs, warfarin (COUMADIN®), heparin, SSRIs or SNRIs, and other blood thinners. **Tell your doctor about all medicines, vitamins and supplements you take.** While taking ELIQUIS, you may bruise more easily and it may take longer than usual for any bleeding to stop.
- Get medical help right away if you have any of these signs or symptoms of bleeding:
  - unexpected bleeding, or bleeding that lasts a long time, such as unusual bleeding from the gums; nosebleeds that happen often, or menstrual or vaginal bleeding that is heavier than normal
  - bleeding that is severe or you cannot control
  - red, pink, or brown urine; red or black stools (looks like tar)
  - coughing up or vomiting blood or vomit that looks like coffee grounds
  - unexpected pain, swelling, or joint pain; headaches, feeling dizzy or weak
- **ELIQUIS is not for patients with artificial heart valves.**
- **Spinal or epidural blood clots or bleeding (hematoma).** People who take ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis).

I focused on finding something better than warfarin.

NOW I TAKE ELIQUIS® (apixaban) FOR 3 GOOD REASONS:

1. ELIQUIS reduced the risk of stroke better than warfarin.
2. ELIQUIS had less major bleeding than warfarin.
3. Unlike warfarin, there's no routine blood testing.

ELIQUIS and other blood thinners increase the risk of bleeding which can be serious, and rarely may lead to death.

Ask your doctor if ELIQUIS is right for you.

This risk is higher if, an epidural catheter is placed in your back to give you certain medicine, you take NSAIDs or blood thinners, you have a history of difficult or repeated epidural or spinal punctures. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.

- **Before you take ELIQUIS,** tell your doctor if you have: kidney or liver problems, any other medical condition, or ever had bleeding problems. Tell your doctor if you are pregnant or breastfeeding, or plan to become pregnant or breastfeed.

- **Do not take ELIQUIS if you** currently have certain types of abnormal bleeding or have had a serious allergic reaction to ELIQUIS. A reaction to ELIQUIS can cause hives, rash, itching, and possibly trouble breathing. Get medical help right away if you have sudden chest pain or chest tightness, have sudden swelling of your face or tongue, have trouble breathing, wheezing, or feeling dizzy or faint.

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch, or call 1-800-FDA-1088.

Please see additional Important Product Information on the adjacent page.

Individual results may vary.

Visit ELIQUIS.COM
or call 1-855-ELIQUIS

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432US14BR00451-02-01 04/14

Eliquis®
(apixaban) tablets 5mg 2.5mg

IMPORTANT FACTS about ELIQUIS® (apixaban) tablets

℞ ONLY

The information below does not take the place of talking with your healthcare professional. Only your healthcare professional knows the specifics of your condition and how ELIQUIS may fit into your overall therapy. Talk to your healthcare professional if you have any questions about ELIQUIS (pronounced ELL eh kwiss).

What is the most important information I should know about ELIQUIS (apixaban)?

For people taking ELIQUIS for atrial fibrillation: Do not stop taking ELIQUIS without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke. ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.

ELIQUIS can cause bleeding which can be serious, and rarely may lead to death. This is because ELIQUIS is a blood thinner medicine that reduces blood clotting.

You may have a higher risk of bleeding if you take ELIQUIS and take other medicines that increase your risk of bleeding, such as aspirin, nonsteroidal anti-inflammatory drugs (called NSAIDs), warfarin (COUMADIN®), heparin, selective serotonin reuptake inhibitors (SSRIs) or serotonin norepinephrine reuptake inhibitors (SNRIs), and other medicines to help prevent or treat blood clots.

Tell your doctor if you take any of these medicines. Ask your doctor or pharmacist if you are not sure if your medicine is one listed above.

While taking ELIQUIS:

- you may bruise more easily
- it may take longer than usual for any bleeding to stop

Call your doctor or get medical help right away if you have any of these signs or symptoms of bleeding when taking ELIQUIS:

- unexpected bleeding, or bleeding that lasts a long time, such as:
- unusual bleeding from the gums
- nosebleeds that happen often
- menstrual bleeding or vaginal bleeding that is heavier than normal
- bleeding that is severe or you cannot control
- red, pink, or brown urine
- red or black stools (looks like tar)
- cough up blood or blood clots
- vomit blood or your vomit looks like coffee grounds
- unexpected pain, swelling, or joint pain
- headaches, feeling dizzy or weak

ELIQUIS (apixaban) is not for patients with artificial heart valves.

Spinal or epidural blood clots or bleeding (hematoma). People who take a blood thinner medicine (anticoagulant) like ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis). Your risk of developing a spinal or epidural blood clot is higher if:

- a thin tube called an epidural catheter is placed in your back to give you certain medicine
- you take NSAIDs or a medicine to prevent blood from clotting
- you have a history of difficult or repeated epidural or spinal punctures
- you have a history of problems with your spine or have had surgery on your spine

If you take ELIQUIS and receive spinal anesthesia or have a spinal puncture, your doctor should watch you closely for symptoms of spinal or epidural blood clots or bleeding. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.

What is ELIQUIS?

ELIQUIS is a prescription medicine used to:

- reduce the risk of stroke and blood clots in people who have atrial fibrillation.

(Continued)

Bristol-Myers Squibb | PATIENT ASSISTANCE FOUNDATION

This independent, non-profit organization provides assistance to qualifying patients with financial hardship who generally have no prescription insurance. Contact 1-800-736-0003 or visit www.bmspaf.org for more information.

- reduce the risk of forming a blood clot in the legs and lungs of people who have just had hip or knee replacement surgery.

It is not known if ELIQUIS is safe and effective in children.

Who should not take ELIQUIS (apixaban)?

Do not take ELIQUIS if you:

- currently have certain types of abnormal bleeding
- have had a serious allergic reaction to ELIQUIS. Ask your doctor if you are not sure

What should I tell my doctor before taking ELIQUIS?

Before you take ELIQUIS, tell your doctor if you:

- have kidney or liver problems
- have any other medical condition
- have ever had bleeding problems
- are pregnant or plan to become pregnant. It is not known if ELIQUIS will harm your unborn baby
- are breastfeeding or plan to breastfeed. It is not known if ELIQUIS passes into your breast milk. You and your doctor should decide if you will take ELIQUIS or breastfeed. You should not do both

Tell all of your doctors and dentists that you are taking ELIQUIS. They should talk to the doctor who prescribed ELIQUIS for you, before you have **any** surgery, medical or dental procedure. **Tell your doctor about all the medicines you take, including** prescription and over-the-counter medicines, vitamins, and herbal supplements. Some of your other medicines may affect the way ELIQUIS works. Certain medicines may increase your risk of bleeding or stroke when taken with ELIQUIS.

How should I take ELIQUIS?

Take ELIQUIS exactly as prescribed by your doctor. Take ELIQUIS twice every day with or without food, and do not change your dose or stop taking it unless your doctor tells you to. If you miss a dose of ELIQUIS, take it as soon as you remember, and do not take more than one dose at the same time. **Do not run out of ELIQUIS.**

Refill your prescription before you run out. When leaving the hospital following hip or knee replacement, be sure that you will have ELIQUIS (apixaban) available to avoid missing any doses. **If you are taking ELIQUIS for atrial fibrillation, stopping ELIQUIS may increase your risk of having a stroke.**

What are the possible side effects of ELIQUIS?

- See **"What is the most important information I should know about ELIQUIS?"**
- ELIQUIS can cause a skin rash or severe allergic reaction. Call your doctor or get medical help right away if you have any of the following symptoms:
  - chest pain or tightness
  - swelling of your face or tongue
  - trouble breathing or wheezing
  - feeling dizzy or faint

Tell your doctor if you have any side effect that bothers you or that does not go away.

These are not all of the possible side effects of ELIQUIS. For more information, ask your doctor or pharmacist.

Call your doctor for medical advice about side effects. You may report side effects to FDA at 1-800-FDA-1088.

This is a brief summary of the most important information about ELIQUIS. For more information, talk with your doctor or pharmacist, call 1-855-ELIQUIS (1-855-354-7847), or go to www.ELIQUIS.com.

Manufactured by:
Bristol-Myers Squibb Company
Princeton, New Jersey 08543 USA

Marketed by:
Bristol-Myers Squibb Company
Princeton, New Jersey 08543 USA
and
Pfizer Inc
New York, New York 10017 USA

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March 2014

432US14BR00770-03-01

Assignment: The Moment

We asked readers to capture fleeting scenes from the world in motion. For future assignments, visit *ngm.com/yourshot/assignments*.

EDITORS' CHOICE

Chris Schmid Monnaz, Switzerland

During a trip to Brazil, Schmid wanted to see the country's famously strong criollo horses. He knew that ranchers would drive a group of horses from one place to another, so he set up a camera with a remote trigger on a hill. Several horses came close to stepping on it, but none did.

READERS' CHOICE

Alex Geifman Lod, Israel

Every day for two months Geifman went to Israel's Ben Shemen Forest to photograph the same pack of foxes. While he was sitting in his car one day, two foxes climbed a tree. Then one slipped. Geifman snapped several shots before the fox fell.

I FINALLY EARNED ENOUGH

MILES TO FLY TO NYC.

THEN THEY RAISED THE MILES

REQUIRED TO FLY TO NYC.

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Millions Demand America's Purest Silver Dollar. Shouldn't You?

Secure Your New 2014 Eagle Silver Dollars Now!

Millions of people collect the American Eagle Silver Dollar. In fact it's been the country's most popular Silver Dollar for over two decades. Try as they might, that makes it a very hard "secret" to keep quiet. And right now, many of those same people are lining up to secure the brand new 2014 U.S. Eagle Silver Dollars — placing their orders now to ensure that they get America's newest Silver Dollar —in stunning Brilliant Uncirculated condition — before millions of others beat you to it.

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Silver is by far the most affordable of all precious metals — and each full Troy ounce American Eagle Silver Dollar is **government-guaranteed** for its 99.9% purity, authenticity, and legal tender status.

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NEXT

Tiny Turbine

In the world of tomorrow, charging your cell phone could be a breeze.

Last year electrical engineers J-C Chiao and Smitha Rao, and their University of Texas at Arlington team, developed a prototype of a wind turbine—half the size of a grain of rice—that could be integrated into future electronics. Made from durable metal alloy and connected by tiny wires, it would deliver a tiny burst of energy to compact devices—think smartphones, not refrigerators—that need quick juice.

It's the latest mobile-technology idea aimed at making power outlets obsolete. Solar backpacks that charge handheld devices already exist. Next up? A new generation of wearable energy sources could include solar-powered fabrics and wind-powered hats that restoke a phone battery. *—Daniel Stone*

SKYCAST

Overhead this month in parts of the world

July 16
Mercury and Venus in the sky together

July 28
Delta Aquarids meteor shower

A wind turbine mounted on metal is dwarfed by a harvester ant. It may one day keep cell phones powered.

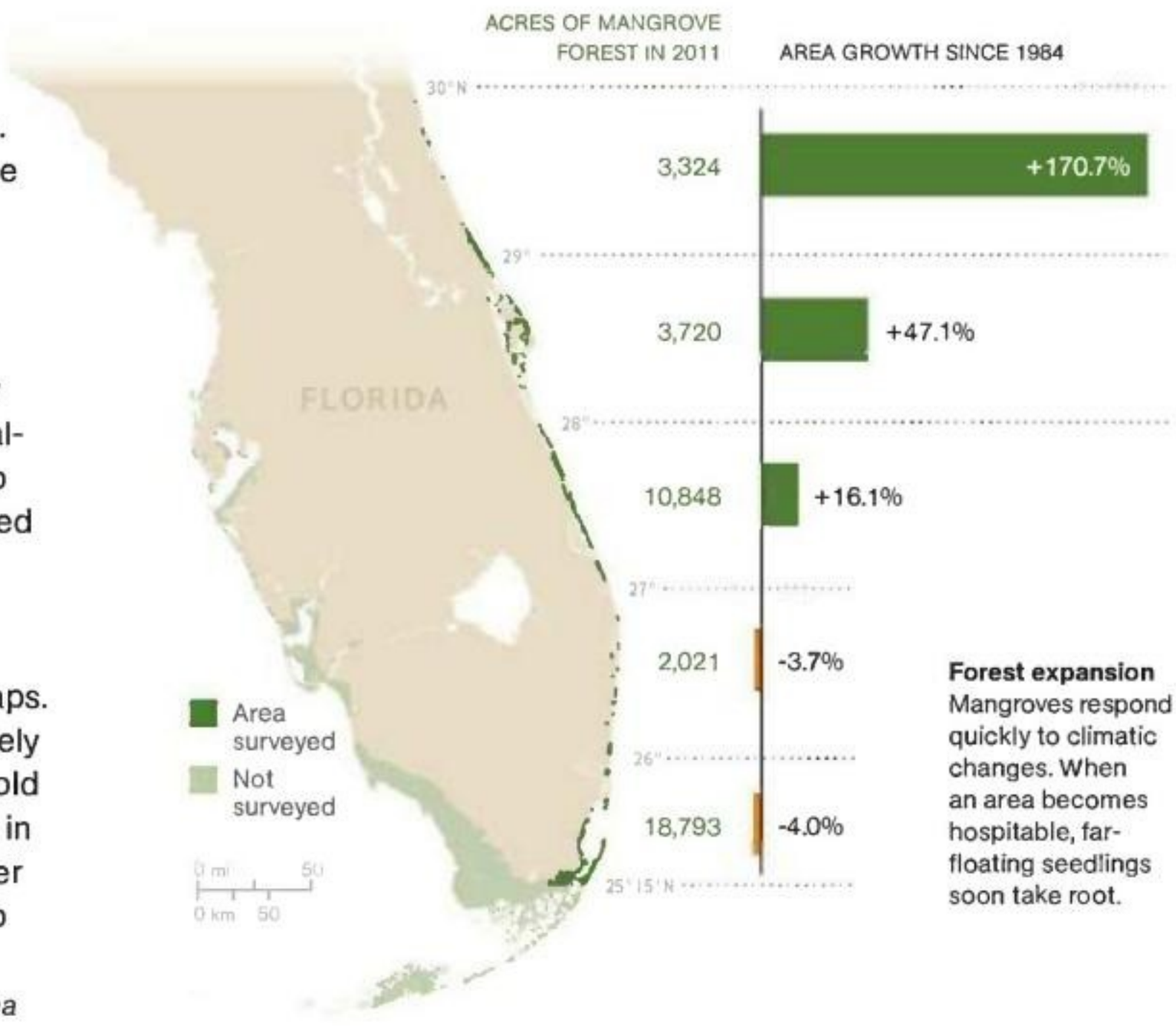
1
Actual size

PHOTO ILLUSTRATION: ADAM VOORHES

Uprooted

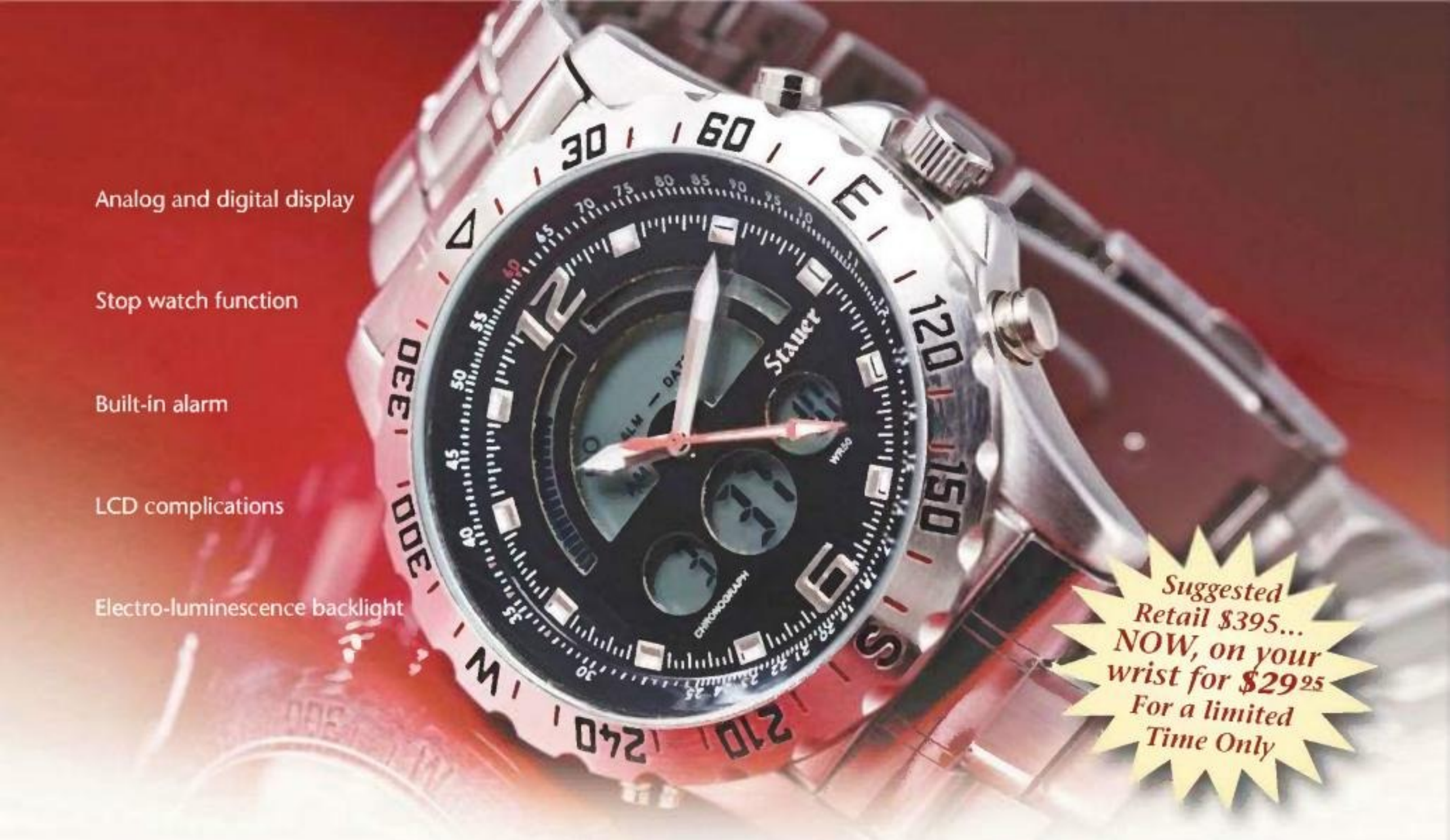
Mangroves are on the march. In recent years scientists have observed the tangled trees growing farther north along Florida's Atlantic coast, but it wasn't until a team of U.S. researchers examined yearly satellite images that they realized the extent. From 1984 to 2011 mangrove forests doubled in size at the northern end of their Florida range.

What's enticing the mangroves north? Fewer cold snaps. These days temperatures rarely dip below 25°F, a vital threshold for the trees. "Small changes in temperature," says researcher Kyle Cavanaugh, "can lead to landscape-scale changes in habitat." *—Rachel Hartigan Shea*



Forest expansion Mangroves respond quickly to climatic changes. When an area becomes hospitable, far-floating seedlings soon take root.

PHOTO: CARLTON WARD, JR. MAP: RYAN MORRIS, NGM STAFF. SOURCES: KYLE C. CAVANAUGH, BROWN UNIVERSITY AND THE SMITHSONIAN ENVIRONMENTAL RESEARCH CENTER; JAMES R. KELLNER, BROWN UNIVERSITY



Amazing New Hybrid Runs Without Gas

The new face of time? Stauer's Compendium Hybrid fuses form and functionality for UNDER $30! Read on...

Innovation is the path to the future. Stauer takes that seriously. That's why we developed the ***Compendium Hybrid***, a stunningly-designed hybrid chronograph with over one dozen analog and digital functions that is more versatile than any watch that we have ever engineered.

New technology usually starts out at astronomical prices and then comes down years later. We skipped that step to allow everyone the chance to experience this watch's brilliant fusion of technology and style. We originally priced the Stauer ***Compendium Hybrid*** at $395 based on the market for advanced sports watches... but then stopped ourselves. Since this is no ordinary economy, we decided to start at 92% off from day one. That means this new technological marvel can be yours for only $29!

Welcome a new Digital Revolution. With the release of the dynamic new ***Compendium***, those boxy, plastic wrist calculators of the past have been replaced by this luxurious LCD chronograph that is sophisticated enough for a formal evening out, but rugged and tough enough to feel at home in a cockpit, camping expedition or covert mission.

The watch's extraordinary dial seamlessly blends an analog watch face with a stylish digital display. Three super-bright luminous hands keep time along the inner dial, while a trio of circular LCD windows track the hour, minutes and seconds. An eye-catching digital semi-circle animates in time with the second hand and shows the day of the week. The watch also features a rotating bezel, stopwatch and alarm functions and green, electro-luminescence backlight. The ***Compendium Hybrid*** secures with a rugged stainless steel band and is water-resistant to 3 ATM.

Guaranteed to change the way you look at time. At Stauer, we believe that when faced with an uphill economy, innovation and better value will always provide a much-needed boost. Stauer is so confident of their latest hybrid timepiece that we offer a money-back-guarantee. If for any reason you aren't fully impressed by the performance and innovation of the Stauer ***Compendium Hybrid*** for $29, simply return the watch within 30 days for a full refund of the purchase price. The unique design of the ***Compendium*** greatly limits our production, so don't hesitate to order! Remember: progress and innovation wait for no one!

WATCH SPECS: - Three LCD windows show hour, minute and second - Stop watch function - Fits 6 3/4"–8 3/4" wrist - 2 year warranty on movements

92% OFF

Offer Limited to First 2500 Respondents

Compendium Hybrid Watch—~~$395~~

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Precision in the Fields

Agriculture is getting a high-tech makeover. Farmers are increasingly using GPS-equipped machinery supported by computers that organize sophisticated data on plants, soil, and weather. Termed "precision agriculture," this system helps them identify and manage variability within fields. David Schimmelpfennig of the USDA Economic Research Service says that farmers have always made informed choices but that access to more data expands their decision-making toolbox. *—Kelsey Nowakowski*

ANALYSIS

Precision-agriculture technologies allow farmers to gather and analyze data to optimize their land's productivity. Most farmers begin by collecting data about their crop yields.

DATA

HARVESTS
Harvesting combines collect georeferenced data that reveal yield variations within each field.

SOIL MAPS
Farmers collect soil samples from different parts of each field, then create maps by analyzing the soil's structure and chemical properties.

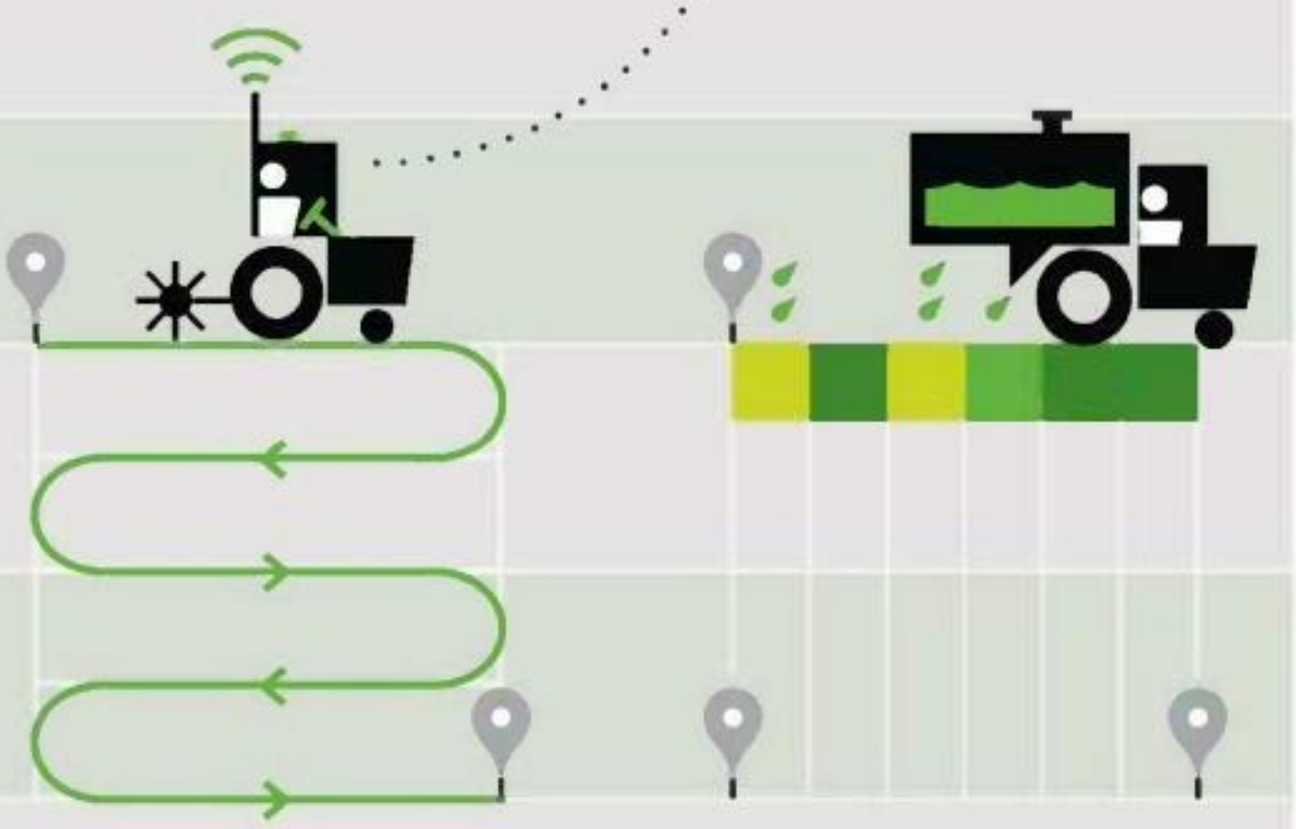
DATA EVALUATION
Computers analyze all the data, helping farmers decide how to make each field as productive as possible.

WEATHER
Weather data provide short- and long-term forecasts for each field. Farmers get information using mobile apps that are updated in real time.

PRESCRIPTION MAPS
Maps generated from the data tell farmers how much seed, fertilizer, and pesticide to use in each area of a field.

Guidance systems can reduce seeding and spraying overlap to less than one inch.

ACTION

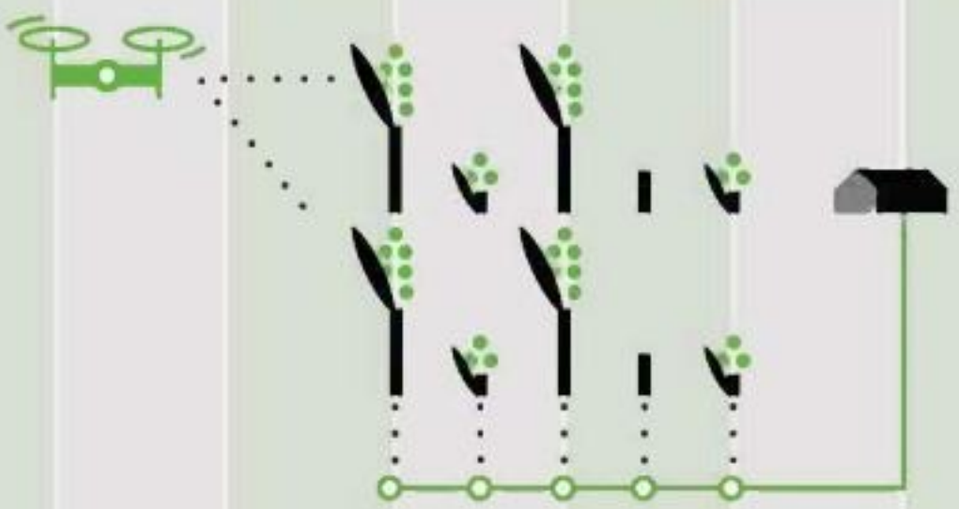


GUIDANCE SYSTEMS

GPS-guided systems help farmers steer machinery more easily and accurately, reducing their fatigue and letting them work longer.

VARY APPLICATIONS

Variable-rate technology places proper amounts of fertilizer and pesticide on each part of a field, depending on how much is needed.

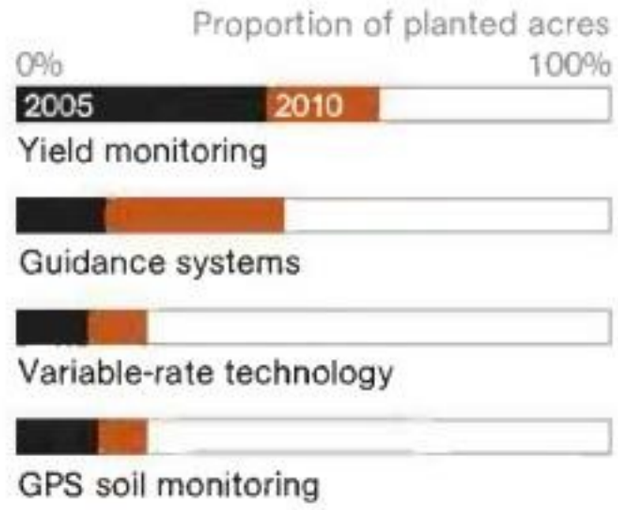


MONITOR

Farmers use monitors and other sensing technology—including drones—to track field conditions such as soil moisture.

ADOPTION RATES

PRECISION-AGRICULTURE TECH USED ON CORN ACREAGE



BENEFITS

Gains for farmers using guidance systems and variable-rate technology

SMALL FARM	TYPICAL	LARGE
800 acres	1,600	2,400

GROSS ANNUAL BENEFIT

$11,000

$26,000

$39,000

YEARS FOR TECHNOLOGY TO PAY FOR ITSELF

GRAPHICS: ÁLVARO VALIÑO. SOURCES: USDA ECONOMIC RESEARCH SERVICE; KEVIN DHUYVETTER, KANSAS STATE UNIVERSITY

In(vasive) Vogue

Alligator and calfskin are so last season. An edgier choice? Wearing invasive species.

Conservation and raising awareness in the fashion industry are the goals, says New Orleans artist Cree McCree. Her clothing made from nutria—a South American rodent that's been wreaking havoc in Louisiana wetlands for decades—has been featured in major runway shows. Paris-based designer Monika Jarosz has a cult following for her purses and wrist cuffs crafted from cane toad, a poisonous amphibian, also South American, introduced to Australia in the 1930s.

Detractors argue that wearing invasive species isn't more ethical than wearing other animals. For Jarosz and others, turning a pest into a product is a fashion-forward form of recycling. *—Catherine Zuckerman*

Wearable species on display: Burmese python–bone ring and earring, cane-toad cuff, wild boar–tooth necklace

PHOTO: REBECCA HALE, NGM STAFF

"I WAS PRESCRIBED LYRICA FOR MY **DIABETIC NERVE PAIN** AND IT HELPED ME. I'M GRATEFUL FOR IT."

—MICHAEL, FORMER PRO GOLFER
DIAGNOSED WITH DIABETIC NERVE PAIN.

Diabetes damages nerves which may cause pain.

Lyrica is FDA approved to treat Diabetic Nerve Pain.

Artist depiction

Get specific treatment for Diabetic Nerve Pain.

LYRICA®
PREGABALIN Ⓒ
capsules

Diabetic Nerve Pain (or pain from Diabetic Peripheral Neuropathy) is characterized by shooting, burning, pins and needles symptoms.

Lyrica has been clinically proven to provide effective pain relief so patients felt better.*

Some patients also had a significant reduction of pain in as early as one week. And, Lyrica is not a narcotic.**

Ask your doctor about Lyrica today.

*Individual results may vary. **Those who have had a drug or alcohol problem may be more likely to misuse Lyrica.
We asked Michael to tell us about his experience with Lyrica. To hear Michael's story, visit Lyrica.com.

Prescription Lyrica is not for everyone. Tell your doctor right away about any serious allergic reaction that causes swelling of the face, mouth, lips, gums, tongue, throat, or neck or any trouble breathing, rash, hives or blisters. Lyrica may cause suicidal thoughts or actions in a very small number of people. Patients, family members or caregivers should call the doctor right away if they notice suicidal thoughts or actions, thoughts of self harm, or any unusual changes in mood or behavior. These changes may include new or worsening depression, anxiety, restlessness, trouble sleeping, panic attacks, anger, irritability, agitation, aggression, dangerous impulses or violence, or extreme increases in activity or talking. If you have suicidal thoughts or actions, do not stop Lyrica without first talking to your doctor. Lyrica may cause swelling of your hands, legs and feet. Some of the most common side effects of Lyrica are dizziness and sleepiness. Do not drive or work with machines until you know how Lyrica affects you. Other common side effects are blurry vision, weight gain, trouble concentrating, dry mouth, and feeling "high." Also, tell your doctor right away about muscle pain along with feeling sick and feverish, or any changes in your eyesight including blurry vision or any skin sores if you have diabetes. You may have a higher chance of swelling, hives or gaining weight if you are also taking certain diabetes or high blood pressure medicines. Do not drink alcohol while taking Lyrica. You may have more dizziness and sleepiness if you take Lyrica with alcohol, narcotic pain medicines, or medicines for anxiety. If you have had a drug or alcohol problem, you may be more likely to misuse Lyrica. Tell your doctor if you are planning to father a child. Talk with your doctor before you stop taking Lyrica or any other prescription medication.

Please see Important Risk Information for Lyrica on the following page.

To learn more visit www.lyrica.com or call toll-free 1-888-9-LYRICA (1-888-959-7422).

You are encouraged to report negative side effects of prescription drugs to the FDA.
Visit www.FDA.gov/medwatch or call 1-800-FDA-1088.

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IMPORTANT FACTS

LYRICA® PREGABALIN © capsules

(LEER-i-kah)

IMPORTANT SAFETY INFORMATION ABOUT LYRICA

LYRICA may cause serious, even life threatening, allergic reactions.
Stop taking LYRICA and call your doctor right away if you have any signs of a serious allergic reaction:
- Swelling of your face, mouth, lips, gums, tongue, throat or neck
- Have any trouble breathing
- Rash, hives (raised bumps) or blisters

Like other antiepileptic drugs, LYRICA may cause suicidal thoughts or actions in a very small number of people, about 1 in 500.
Call your doctor right away if you have any symptoms, especially if they are new, worse or worry you, including:
- suicidal thoughts or actions
- new or worse depression
- new or worse anxiety
- feeling agitated or restless
- panic attacks
- trouble sleeping
- new or worse irritability
- acting aggressive, being angry, or violent
- acting on dangerous impulses
- an extreme increase in activity and talking
- other unusual changes in behavior or mood

If you have suicidal thoughts or actions, do not stop LYRICA without first talking to your doctor.

LYRICA may cause swelling of your hands, legs and feet.
This swelling can be a serious problem with people with heart problems.

LYRICA may cause dizziness or sleepiness.
Do not drive a car, work with machines, or do other dangerous things until you know how LYRICA affects you. Ask your doctor when it is okay to do these things.

ABOUT LYRICA

LYRICA is a prescription medicine used in adults 18 years and older to treat:
- Pain from damaged nerves that happens with diabetes or that follows healing of shingles, or spinal cord injury
- Partial seizures when taken together with other seizure medicines
- Fibromyalgia (pain all over your body)

Who should NOT take LYRICA:
- Anyone who is allergic to anything in LYRICA

BEFORE STARTING LYRICA

Tell your doctor about all your medical conditions, including if you:
- Have had depression, mood problems or suicidal thoughts or behavior
- Have or had kidney problems or dialysis
- Have heart problems, including heart failure
- Have a bleeding problem or a low blood platelet count
- Have abused prescription medicines, street drugs or alcohol in the past
- Have ever had swelling of your face, mouth, tongue, lips, gums, neck, or throat (angioedema)
- Plan to father a child. It is not known if problems seen in animal studies can happen in humans.
- Are pregnant, plan to become pregnant or are breastfeeding. It is not known if LYRICA will harm your unborn baby. You and your doctor should decide whether you should take LYRICA or breast-feed, but you should not do both.

Tell your doctor about all your medicines. Include over-the-counter medicines, vitamins, and herbal supplements. LYRICA and other medicines may affect each other causing side effects. Especially tell your doctor if you take:

BEFORE STARTING LYRICA, continued

- Angiotensin converting enzyme (ACE) inhibitors. You may have a higher chance for swelling and hives.
- Avandia® (rosiglitazone)*, Avandamet® (rosiglitazone and metformin)* or Actos® (pioglitazone)** for diabetes. You may have a higher chance of weight gain or swelling of your hands or feet.
- Narcotic pain medicines (such as oxycodone), tranquilizers or medicines for anxiety (such as lorazepam). You may have a higher chance for dizziness and sleepiness.
- Any medicines that make you sleepy.

POSSIBLE SIDE EFFECTS OF LYRICA

LYRICA may cause serious side effects, including:
- See "Important Safety Information About LYRICA."
- Muscle problems, pain, soreness or weakness along with feeling sick and fever
- Eyesight problems including blurry vision
- Weight gain. Weight gain may affect control of diabetes and can be serious for people with heart problems.
- Feeling "high"

If you have any of these symptoms, tell your doctor right away.

The most common side effects of LYRICA are:
- Dizziness
- Blurry vision
- Weight gain
- Sleepiness
- Trouble concentrating
- Swelling of hands and feet
- Dry mouth

If you have diabetes, you should pay extra attention to your skin while taking LYRICA.

HOW TO TAKE LYRICA

Do:
- Take LYRICA exactly as your doctor tells you. Your doctor will tell you how much to take and when to take it. Take LYRICA at the same times each day.
- Take LYRICA with or without food.

Don't:
- Drive a car or use machines if you feel dizzy or sleepy while taking LYRICA.
- Drink alcohol or use other medicines that make you sleepy while taking LYRICA.
- Change the dose or stop LYRICA suddenly.
  If you stop taking LYRICA suddenly, you may have headaches, nausea, diarrhea, trouble sleeping, increased sweating, or you may feel anxious. If you have epilepsy, you may have seizures more often.
- Start any new medicines without first talking to your doctor.

NEED MORE INFORMATION?

- Ask your doctor or pharmacist. This is only a brief summary of important information.
- Go to **www.lyrica.com** or call **1-866-459-7422 (1-866-4LYRICA).**

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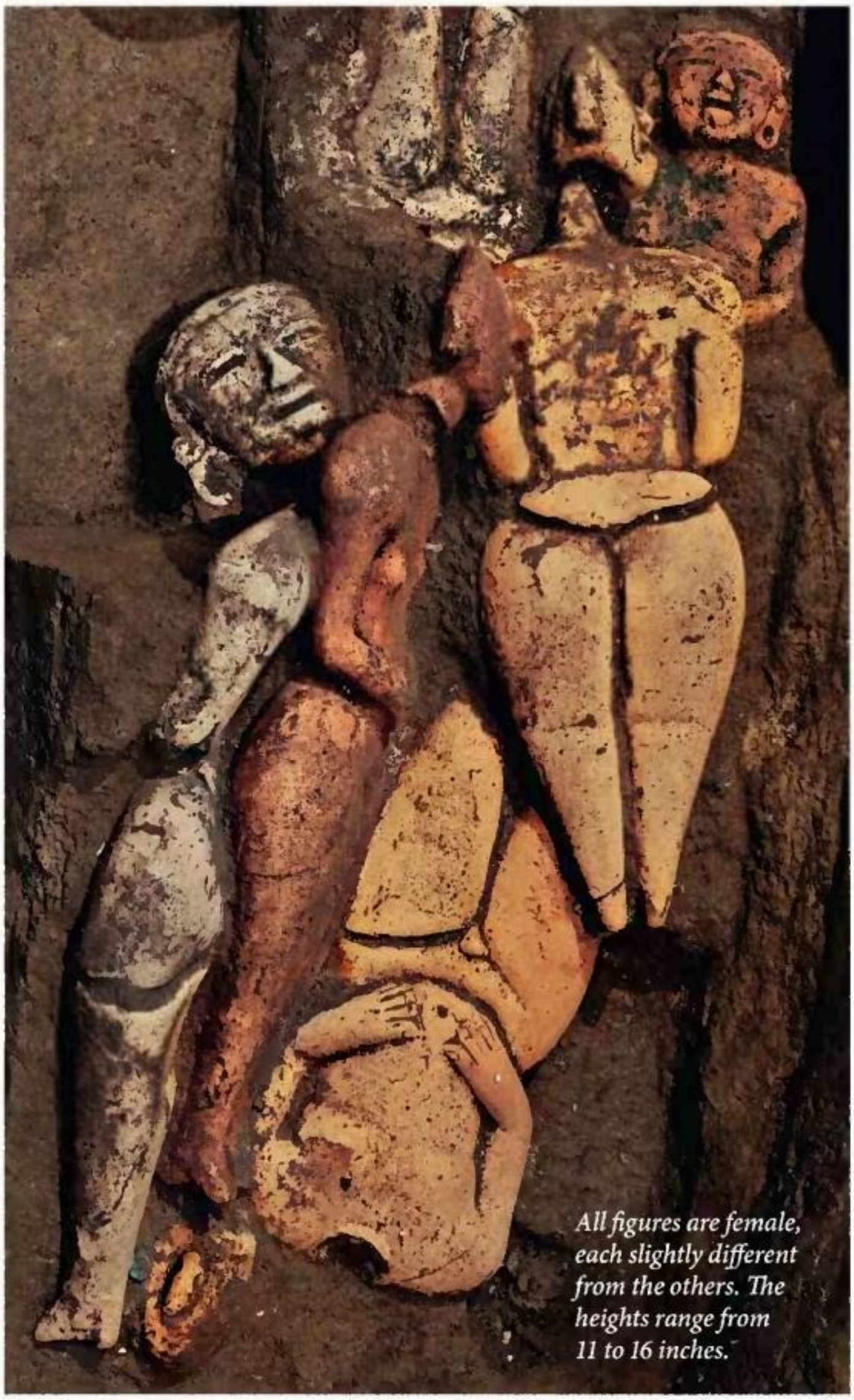
Migrants make up about 3.2 percent of the planet's population.



All figures are female, each slightly different from the others. The heights range from 11 to 16 inches.

The King's Maidens

Six ceramic figurines were a puzzle when they came to light in a royal Maya tomb at Takalik Abaj in Guatemala in 2012. Now archaeologist Christa Schieber de Lavarreda and her team believe they have worked out the complex symbolism. "They're like marionettes in a theater," she says. One role was to accompany the king to the underworld in about 500 B.C.

But they also played other parts. Four stood at the cardinal points, the corners of the Maya universe. Two others, positioned east and west, likely represented the daily cycle of the rising and setting sun. That symbol of constant rebirth may allude to the staple crop of corn sprouting anew every year—a nod to the king's own mythical role as the corn god. *—A. R. Williams*

ET CETERA

Large **ACID RAIN** storms may have followed the asteroid strike that killed the dinosaurs some 65 million years ago, says one study, one reason only some species survived. • Oceanographers have found an unknown **COLD-WATER CORAL** near southern Greenland, where water temperatures are close to freezing. • A **ZIRCON** rock discovered in Australia contains crystals believed to be 4.4 billion years old, the oldest material ever found on Earth.

PHOTO: KENNETH GARRETT, MADE WITH PERMISSION OF TAK'ALIK AB'AJ NATIONAL ARCHAEOLOGICAL PARK/ GUATEMALAN MINISTRY OF CULTURE AND SPORTS. NGM MAPS. GRAPHIC: ÁLVARO VALIÑO. SOURCE: UNITED NATIONS

THE HUNT FOR

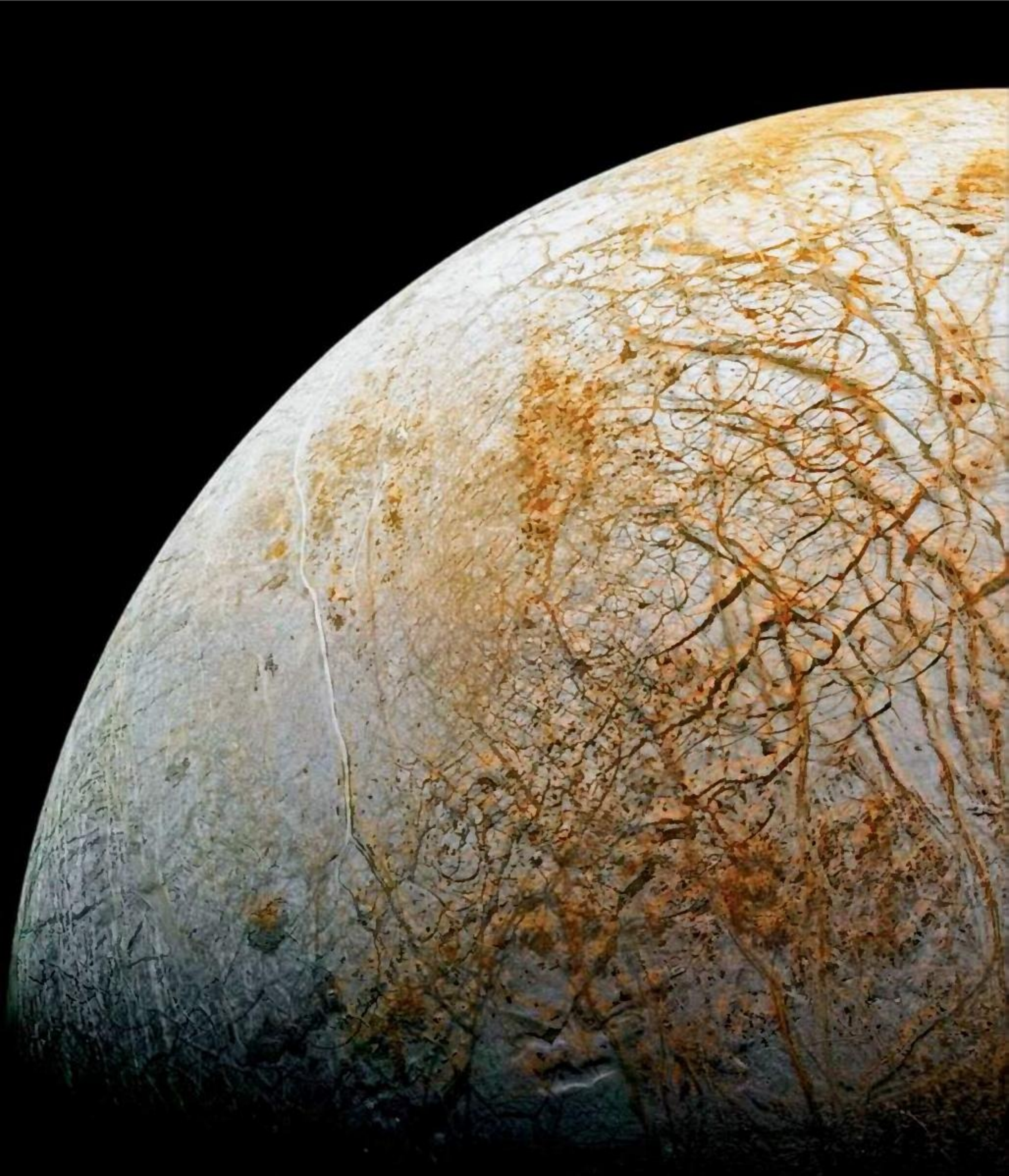
LIFE BEYOND EARTH

ONE OF THE OLDEST QUESTIONS MAY BE

ANSWERED IN OUR LIFETIMES.

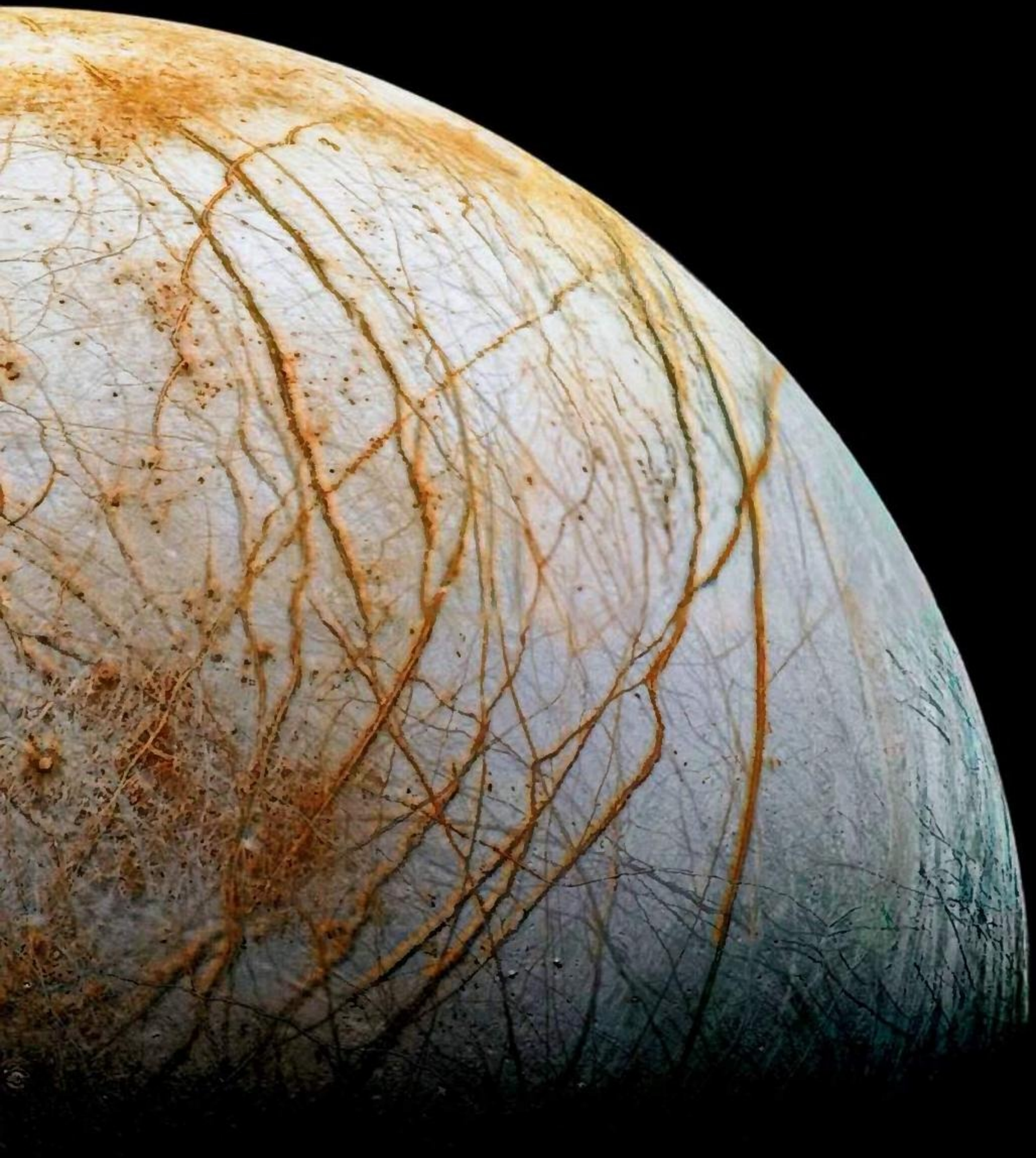
ARE WE ALONE?

Scientists at NASA's Jet Propulsion Laboratory (JPL) inspect a probe
like one that might someday travel beneath the ice of Jupiter's moon Europa.



Europa's frozen, fissured surface, seen here in a colorized mosaic image from the Galileo spacecraft, hides a

GALILEO PROJECT/NASA/JPL; REPROCESSED BY TED STRYK



liquid ocean that may hold all the ingredients needed for life.

BY MICHAEL D. LEMONICK

PHOTOGRAPHS BY MARK THIESSEN

An electronic signal

travels from NASA's Jet Propulsion Lab in Pasadena, California, to a robotic rover clinging to the underside of foot-thick ice on an Alaskan lake. The rover's spotlight begins to glow. "It worked!" exclaims John Leichty, a young JPL engineer huddled in a tent on the lake ice nearby. It may not sound like a technological tour de force, but this could be the first small step toward the exploration of a distant moon.

More than 4,000 miles to the south, geomicrobiologist Penelope Boston sloshes through murky, calf-deep water in a pitch-dark cavern in Mexico, more than 50 feet underground. Like the other scientists with her, Boston wears an industrial-strength respirator and carries a canister of spare air to cope with the poisonous hydrogen sulfide and carbon monoxide gases that frequently permeate the cave. The rushing water around her feet is laced with sulfuric acid. Suddenly her headlamp illuminates an elongated droplet of thick, semitransparent fluid oozing from the chalky, crumbling wall. "Isn't it cute?" she exclaims.

These two sites—a frozen Arctic lake and a toxic tropical cave—could provide clues to one of the oldest, most compelling mysteries on Earth: Is there life beyond our planet? Life on other worlds, whether in our own solar system or orbiting distant stars, might well have to survive in ice-covered oceans, like those on Jupiter's moon Europa, or in sealed, gas-filled caves, which could be plentiful on Mars. If you can figure out how to isolate and identify life-forms that thrive in similarly extreme surroundings on Earth, you're a step ahead in searching for life elsewhere.

It's difficult to pin down when the search for life among the stars morphed from science fiction to science, but one key milestone was an astronomy meeting in November 1961. It was organized

Astrobiologist Kevin Hand prepares to deploy a rover (pages 34-35) beneath the ice of Alaska's Sukok Lake. When a probe finally reaches Europa, its search for life may be modeled on trial runs like this. And with the powerful SLS rocket NASA is designing, he says, "we could potentially get to Jupiter and Europa very quickly."

by Frank Drake, a young radio astronomer who was intrigued with the idea of searching for alien radio transmissions.

When he called the meeting, the search for extraterrestrial intelligence, or SETI, "was essentially taboo in astronomy," Drake, now 84, remembers. But with his lab director's blessing, he brought in a handful of astronomers, chemists, biologists, and engineers, including a young planetary scientist named Carl Sagan, to discuss what is now called astrobiology, the science of life beyond Earth. In particular, Drake wanted some expert help in deciding how sensible it might be to devote significant radio telescope time to listening for alien broadcasts and what might be the most promising way to search. How many civilizations might reasonably be out there? he wondered. So before his guests arrived, he scribbled an equation on the blackboard.

That scribble, now famous as the Drake equation, lays out a process for answering his question. You start out with the formation rate of sunlike stars in the Milky Way, then multiply that by the fraction of such stars that have planetary systems. Take the resulting number and multiply that by the number of life-friendly planets on average in each such system—planets, that is, that are about the size of Earth and orbit at the right distance from their star to be hospitable to life. Multiply that by the fraction of those planets where life arises, then by the fraction of those where life evolves intelligence, and then by the fraction of those that might develop the technology to emit radio signals we could detect.

The final step: Multiply the number of radio-savvy civilizations by the average time they're likely to keep broadcasting or even to survive. If such advanced societies typically blow themselves up in a nuclear holocaust just a few decades after developing radio technology, for example, there would probably be very few to listen for at any given time.

The equation made perfect sense, but there was one problem. Nobody had a clue what any of those fractions or numbers were, except for the very first variable in the equation: the formation rate of sunlike stars. The rest was pure guesswork. If SETI scientists managed to snag an extraterrestrial radio signal, of course, these uncertainties wouldn't matter. But until that happened, experts on every item in the Drake equation would have to try to fill it in by nailing down the numbers—by finding the occurrence rate for planets around sunlike stars or by trying to solve the mystery of how life took root on Earth.

It would be a third of a century before scientists could even begin to put rough estimates into the equation. In 1995 Michel Mayor and Didier Queloz of the University of Geneva detected the first planet orbiting a sunlike star outside our solar system. That world, known as 51 Pegasi b, about 50 light-years from Earth, is a huge, gaseous blob about half the size of Jupiter, with an orbit so tight that its "year" is only four days long and its surface temperature close to 2000°F.

Nobody thought for a moment that life could ever take hold in such hellish conditions. But the discovery of even a single planet was an enormous breakthrough. Early the next year Geoffrey Marcy, then at San Francisco State University and now at UC Berkeley, would lead his own team in finding a second extrasolar planet, then a third. After that, the floodgates opened. To date, astronomers have confirmed nearly two thousand so-called exoplanets, ranging in size from smaller than Earth to bigger than Jupiter; thousands more—most found by the exquisitely sensitive Kepler space telescope, which went into orbit in 2009—await confirmation.

None of these planets is an exact match for Earth, but scientists are confident they'll find one that is before too long. Based on the discoveries of somewhat larger planets made to date, astronomers recently calculated that more than a fifth of stars like the sun harbor habitable, Earth-like planets. Statistically speaking, the nearest one could be a mere 12 light-years away, which is practically next door in cosmic terms.

That's good news for astrobiologists. But in recent years planet hunters have realized that there's no reason to limit their search to stars just like our sun. "When I was in high school," says David Charbonneau, an astronomer at Harvard, "we were taught that Earth orbits an average star.

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

The Drake equation, formulated in 1961, estimates the number of alien civilizations we could detect. Recent discoveries of numerous planets in the Milky Way have raised the odds.

But that's a lie." In fact, about 80 percent of the stars in the Milky Way are small, cool, dim, reddish bodies known as M dwarfs. If an Earthlike planet circled an M dwarf at the right distance—it would have to be closer in than the Earth is to our sun to avoid being too cold—it could provide a place where life could gain a foothold just as easily as on an Earthlike planet orbiting a sunlike star.

Moreover, scientists now believe a planet doesn't have to be the same size as Earth to be habitable. "If you ask me," says Dimitar Sasselov, another Harvard astronomer, "anywhere from one to five Earth masses is ideal." In short, the variety of habitable planets and the stars they might orbit is likely to be far greater than what Drake and his fellow conferees conservatively assumed at that meeting back in 1961.

That's not all: It turns out that the range of temperatures and chemical environments where extremophilic organisms might be able to thrive is also greater than anyone at Drake's meeting could have imagined. In the 1970s oceanographers such as National Geographic Explorer-in-Residence Robert Ballard discovered superheated gushers, known as hydrothermal vents, nourishing a rich ecosystem of bacteria. Feasting on hydrogen sulfide and other chemicals dissolved in the water, these microbes in turn feed higher organisms. Scientists have also found life-forms that flourish in hot springs, in frigid lakes thousands of feet below the surface of the Antarctic ice sheet, in highly acidic or highly alkaline or extremely salty or radioactive locations, and even in minute cracks in solid rock a mile or more underground. "On Earth these are niche environments," says Lisa Kaltenegger, who holds joint appointments at Harvard and the Max Planck Institute for Astronomy in Heidelberg, Germany. "But on another planet you can easily envision that they could be dominant scenarios."

THE ONE FACTOR THAT biologists argue is critical for life as we know it is water in liquid form—a powerful solvent capable of transporting dissolved nutrients to all parts of an organism. In our own solar system we've known since the Mariner 9 Mars orbiter mission in 1971 that water once likely flowed freely on the red planet. So life might have existed there, at least in microbial form—and it's plausible that remnants of that life could still endure underground, where liquid water may linger. Jupiter's moon Europa also shows cracks in its relatively young, ice-covered surface—evidence that beneath the ice lies an ocean of liquid water. At a half billion miles or so from the sun, Europa's water should be frozen solid. But this moon is constantly flexing under the tidal push and pull of Jupiter and several of its other moons, generating heat that could keep the water below liquid. In theory, life could exist in that water too.

In 2005 NASA's Cassini spacecraft spotted jets of water erupting from Saturn's moon Enceladus; subsequent measurements by the spacecraft reported in April of this year confirm an underground source of water on that moon as well. Scientists still don't know how much water might be under Enceladus's icy shell, however, or whether it's been liquid long enough to permit life to exist. The surface of Titan, Saturn's

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Michael Lemonick's latest book is Mirror Earth: The Search for Our Planet's Twin. *Mark Thiessen shot our story on the solar system in the July 2013 issue.*

BRUIE (Buoyant Rover for Under-Ice Exploration) crawls along the underside of the surface ice in a test in

Sukok Lake. Bubbles of methane and other compounds signal the presence of life below.

Watch the rover in action on our digital editions.

Based on the discoveries of larger planets, scientists calculated that more than a fifth of stars like our sun harbor Earthlike planets.

largest moon, has rivers, lakes, and rain. But Titan's meteorological cycle is based on liquid hydrocarbons such as methane and ethane, not water. Something might be alive there, but what it would be like is very hard to guess.

Mars is far more Earthlike, and far closer, than any of these distant moons. The search for life has driven virtually every mission to the red planet. The NASA rover Curiosity is currently exploring Gale crater, where a huge lake sat billions of years ago and where it's now clear that the chemical environment would have been hospitable to microbes, if they existed.

A cave in Mexico isn't Mars, of course, and a lake in northern Alaska isn't Europa. But it's the search for extraterrestrial life that has taken JPL astrobiologist Kevin Hand and the other members of his team, including John Leichty, to Sukok Lake, 20 miles from Barrow, Alaska. The same quest has lured Penelope Boston and her colleagues multiple times to the poisonous Cueva de Villa Luz, a cave near Tapijulapa in Mexico. Both sites let the researchers test new techniques for searching for life in environments that are at least broadly similar to what space probes might encounter. In particular, they're looking for biosignatures—visual or chemical clues that signal the presence of life, past or present, in places where scientists won't have the luxury of doing sophisticated laboratory experiments.

Take the Mexican cave. Orbiting spacecraft have shown that caves do exist on Mars, and they're just the sorts of places where microbes might have taken refuge when the planet lost its atmosphere and surface water some three billion years ago. Such Martian cave dwellers would have had to survive on an energy source other than sunlight—like the dripping ooze that has Boston so enchanted. The scientists refer to these unlovely droplets as "snottites." One of thousands in the cave, varying in length from a fraction of an inch to a couple of feet, it does look uncannily like mucus. It's actually a biofilm, a community of microbes bound together in a viscous, gooey blob.

The snottite microbes are chemotrophs, Boston explains. "They oxidize hydrogen sulfide—that's their only energy source—and they produce this goo as part of their lifestyle."

Snottites are just one of the microbial communities that exist here. Boston, of the New Mexico Institute of Mining and Technology and the National Cave and Karst Research Institute, says that all told there are about a dozen communities of microbes in the cave. "Each one has a very distinct physical appearance. Each one is tapping into different nutrient systems."

One of these communities is especially intriguing to Boston and her colleagues. It doesn't form drips or blobs but instead makes patterns on the cave walls, including spots, lines, and even networks of lines that look almost like hieroglyphics. Astrobiologists have come to call these patterns biovermiculations, or bioverms for short, from the word "vermiculation," meaning decorated with "irregular patterns of lines, as though made by worm tracks."

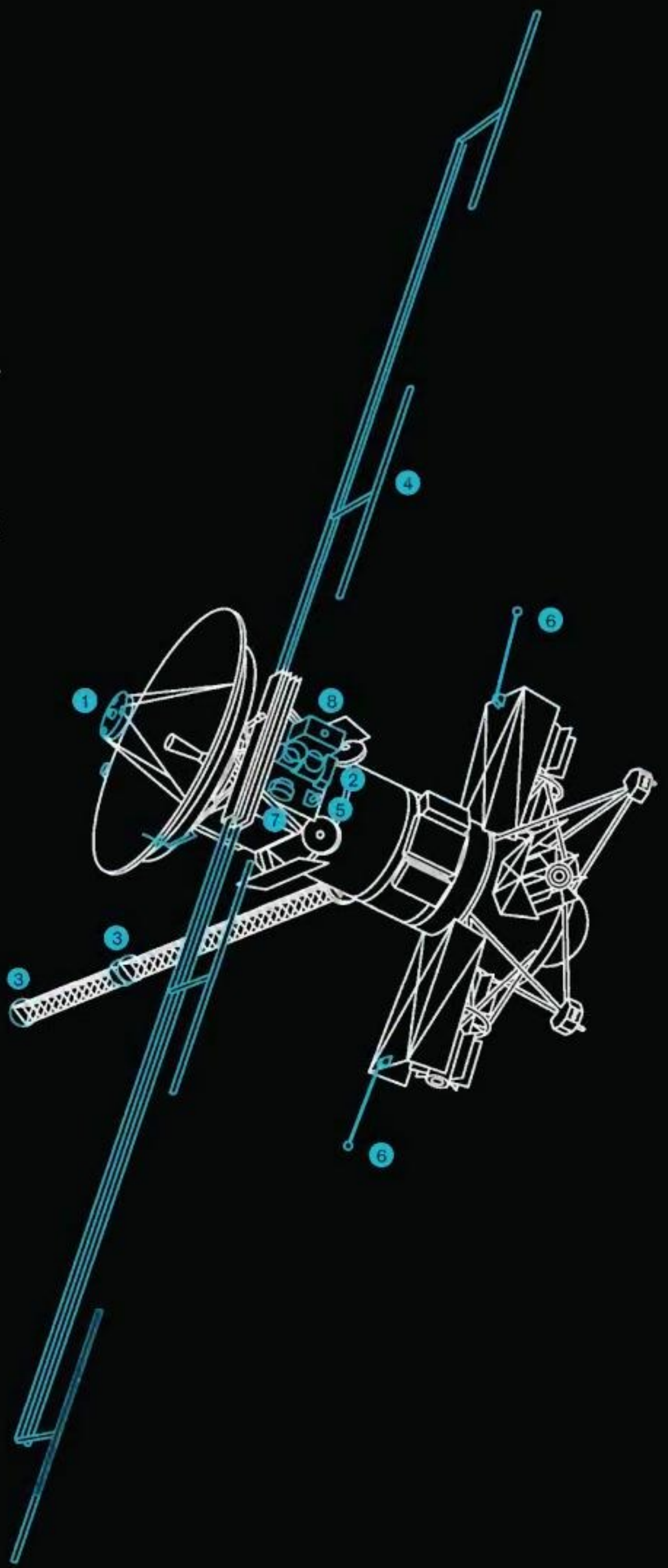
It turns out that patterns like these aren't made only by microorganisms growing on cave walls. "It happens on a variety of different scales, usually in places where some resource is in short supply," says Keith Schubert, a Baylor University engineer who specializes in imaging systems and who came to Cueva de Villa Luz to set up cameras for long-term monitoring inside the cave. Grasses and trees in arid regions create bioverm patterns as well, says Schubert. So do soil crusts, which are communities of bacteria, mosses, and lichens that cover the ground in deserts.

If this hypothesis holds up—and it's still only a hypothesis—then Boston, Schubert, and other

Society Grant Penelope Boston's research was funded in part by your Society membership.

Listening for life

NASA's proposed Clipper spacecraft would fly by Jupiter's moon Europa 45 times, cruising within 16 miles of the surface. Here's how it would seek the conditions for life.



Sniff the atmosphere

A **neutral mass spectrometer (1)** analyzes material ejected from Europa's surface for organic materials related to life and for clues to its ocean's composition.

Sense chemicals

Mapping impurities on Europa's surface with a **shortwave infrared spectrometer (2)** provides further clues about the ocean's makeup. From space the device can also sense chemicals that may be building blocks for life.

Measure salinity

Magnetometers (3) determine the ocean's salinity and depth based on how it responds to Jupiter's magnetic field.

Peek at the ice

Using radio waves, **ice-penetrating radar (4)** looks for liquid in and under Europa's icy shell, and could help determine the thickness of the ice.

Map geology in 3-D

By surveying surface features, a **topographical imager (5)** reveals how geology has shaped Europa's ice and how fluids move within it.

Probe particles

Langmuir probes (6) analyze charged particles in Jupiter's magnetic field that pelt Europa's surface. This bombardment creates oxygen-rich materials that could make their way to the ocean below.

Seek warmth

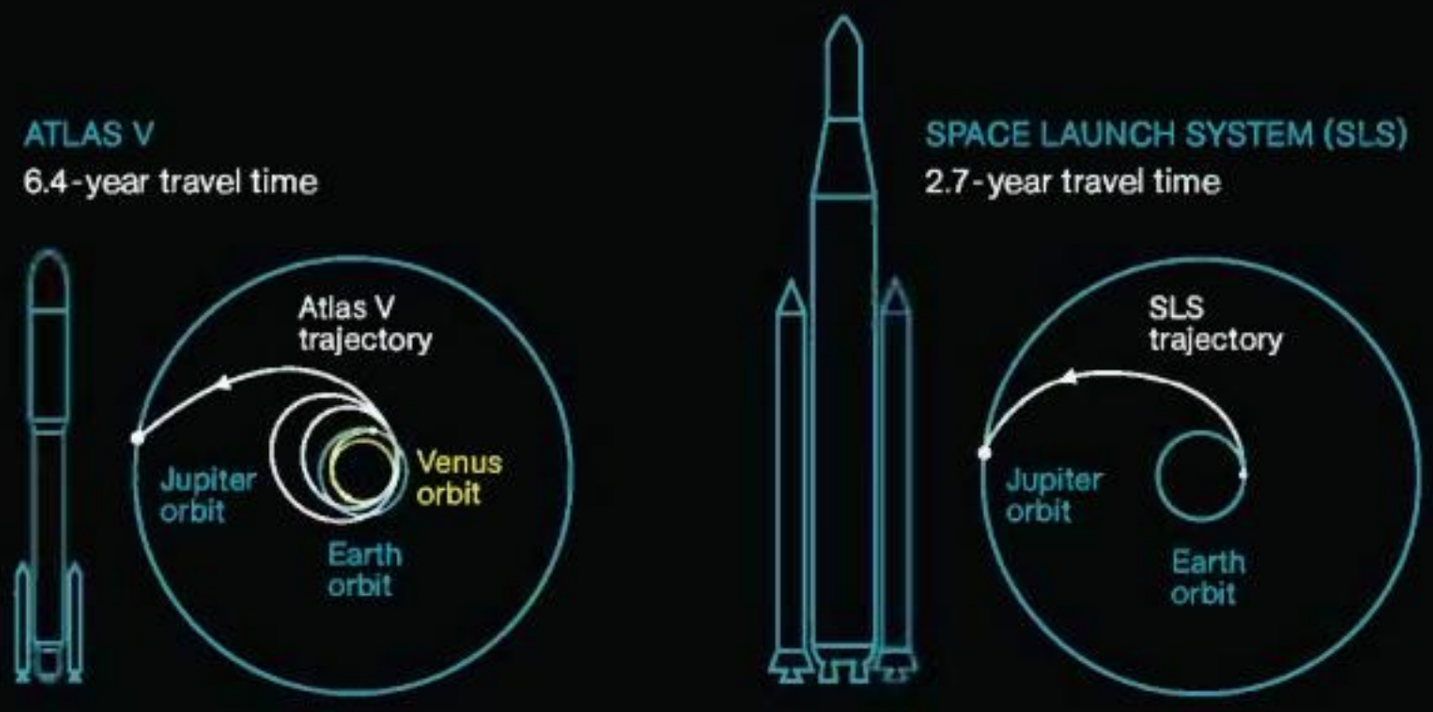
Plume vents and other warm, active surface features can be detected by a **thermal imager (7)**.

Look ahead

A **reconnaissance camera (8)** surveys the surface, looking for smooth places suitable for a future mission that would land on Europa.

TWO WAYS TO JUPITER

To get to Jupiter, the Clipper would either first "slingshot" around Earth and Venus on an Atlas V rocket or travel more directly in less time on the proposed SLS rocket. The hoped-for launch date: 2022.



JOHN TOMANIO, NGM STAFF
CLIPPER ART: HAISAM HUSSEIN
SOURCE: STEVE VANCE, JPL/CALTECH

Distant oasis

Three ingredients are needed for life as we know it: liquid water; essential elements like carbon, nitrogen, and sulfur; and an energy source. Though a half billion miles from the sun, Jupiter's moon Europa has a liquid ocean beneath its icy surface and the right elements on its rocky seafloor. Energy could be provided by compounds on the surface that reach the ocean below.

ABUNDANT HABITAT

Though Europa is only the size of our own moon, it holds more water than all of Earth's oceans.

ART: DANA BERRY
SOURCE: KEVIN HAND, JPL/CALTECH

IO'S CONTRIBUTION

Europa's surface captures sulfur flung into space from its volcanic sister moon Io. Sulfur can be converted into a source of chemical energy for life.

JUPITER'S CRUCIAL ROLE

The tidal push and pull of Jupiter and several of its other moons constantly flexes Europa, generating heat that keeps the water under the ice liquid. Charged particles in Jupiter's magnetic field bombard the surface, converting sulfur and other elements into energy-rich compounds.

LIFE UNDER THE ICE

Only some 60 million years old, Europa's brittle surface appears to be in constant flux. Energy-rich compounds there could reach the ocean as pieces of the crust slide under each other. Plumes and deep fissures may provide other routes into the liquid world beneath.

A microbe retrieved in 2013 from Lake Whillans, half a mile beneath the Antarctic ice, reveals life's ability to take hold even in the most extreme environments.

scientists who are documenting bioverms may have found something crucially important. Until now, many of the markers of life astrobiologists have looked for are gases, like oxygen, that are given off by organisms on Earth. But life that produces an oxygen biosignature may be only one kind among many.

"What excites me about bioverms," says Boston, "is that we've seen them at all these different scales and in all these wildly different environments, and yet the characters of the patterns are very similar." It's highly plausible, she and Schubert believe, that these patterns, based on simple rules of growth and competition for resources, could be literally a universal signature of life. In caves, moreover, even when the microbial communities die, they leave the patterns behind. If a rover should see something like this on the wall of a Martian cave, says Schubert, "it could direct you where to focus your attention."

AT THE OPPOSITE END of North America, the scientists and engineers shivering at Sukok Lake are on a similar mission. They're working at two different locations on the lake, one next to a cluster of three small tents the scientists have dubbed "Nasaville," and the other, with just a single tent, about a half mile away as the crow flies. Because methane gas bubbling from the lake bottom churns up the water, ice has a hard time forming in some places. To snowmobile from one camp to the other, the scientists have to take a curving, indirect route to avoid a potentially fatal dunking.

It was the methane that first drew the scientists to Sukok and other nearby Alaska lakes back in 2009. This common hydrocarbon gas is generated by microbes, known collectively as methanogens, that decompose organic matter, making it another potential biosignature astrobiologists could look for on other worlds. But methane also comes from volcanic eruptions and other nonbiological sources, and it forms naturally in the atmosphere of giant planets like Jupiter as well as on Saturn's moon Titan. So it's crucial that scientists be able to distinguish biological methane from its nonbiological cousin. If you're focused on ice-covered Europa, as Kevin Hand is, ice-covered, methane-rich Sukok Lake isn't a bad place to get your feet wet—as long as you don't do it literally.

Hand, a National Geographic emerging explorer, favors Europa over Mars as a place to do astrobiology, for one key reason. Suppose we do go to Mars, he says, and find living organisms in the subsurface that are DNA based, like life on Earth. That could mean that DNA is a universal molecule of life, which is certainly possible. But it could also mean that life on Earth and life on Mars share a common origin. We know for certain that rocks blasted off the surface of Mars by asteroid impacts have ended up on Earth. It's also likely that Earth rocks have traveled to Mars. If living microbes were trapped inside such spacefaring rocks and survived the journey, which is at least plausible, they could have seeded whichever planet they ended up on. "If life on Mars were found to be DNA based," says Hand, "I think we would have some confusion as to whether or not that was a separate origin of DNA." But Europa is vastly farther away. If life were found there, it would point to a second, independent origin—even if it were DNA based.

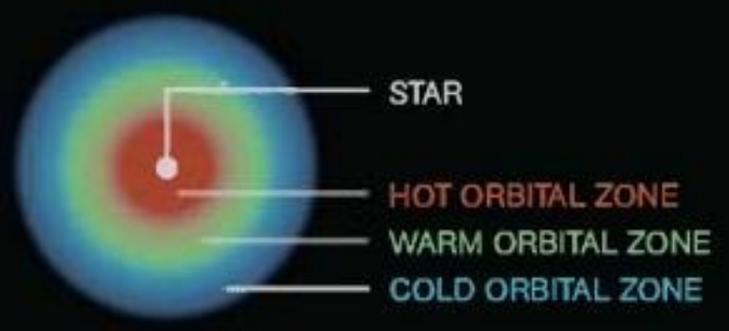
Europa certainly seems to have the basic ingredients for life. Liquid water is abundant, and the ocean floor may also have hydrothermal vents, similar to Earth's, that could provide nutrients for

TRISTA VICK-MAJORS AND PAMELA SANTIBÁÑEZ, PRISCU RESEARCH GROUP, MONTANA STATE UNIVERSITY, BOZEMAN

Microbe-rich biofilms—referred to as snottites—drip from the sunless walls of Cueva de Villa Luz in Mexico. Living off sulfur compounds, the microbes in turn feed midges that live in the cave.

Goldilocks worlds: just right for life?

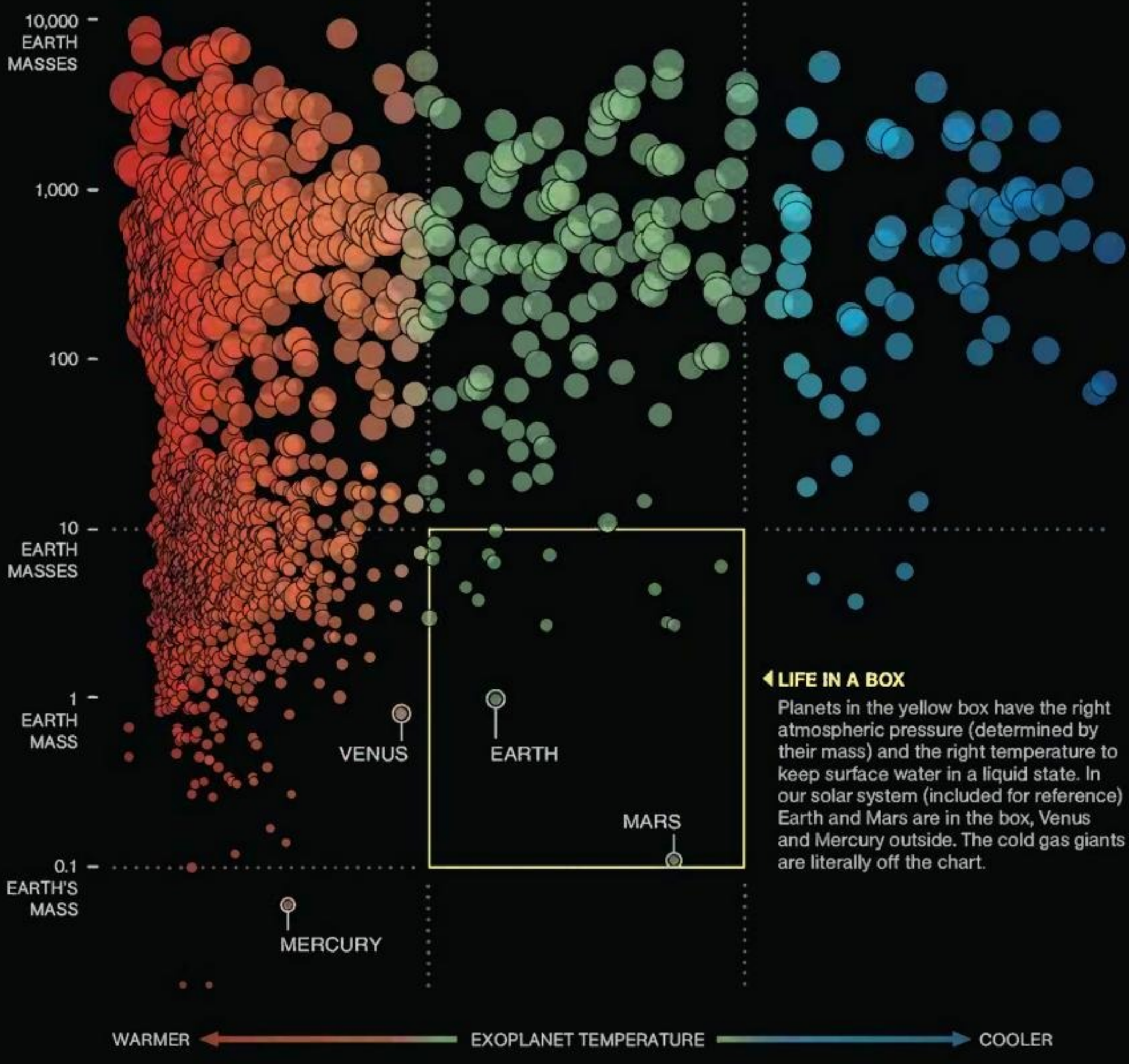
Among the 1,771* confirmed planets beyond our solar system, up to 14 are located in their star's habitable zone, where conditions are neither too hot nor too cold to support life. Size also matters: A planet that's too small can't maintain an atmosphere; one that's too large will have a crushing atmosphere.



HOT ORBITAL ZONE
On planets too close to their respective suns, surface water evaporates into space.

WARM ORBITAL ZONE
On planets that have water, it can remain liquid, given the right atmospheric pressure.

COLD ORBITAL ZONE
Here planets are too far from their suns, so any surface water remains frozen.



◀ LIFE IN A BOX
Planets in the yellow box have the right atmospheric pressure (determined by their mass) and the right temperature to keep surface water in a liquid state. In our solar system (included for reference) Earth and Mars are in the box, Venus and Mercury outside. The cold gas giants are literally off the chart.

WARMER ← EXOPLANET TEMPERATURE → COOLER

*AS OF MARCH 17, 2014

JOHN TOMANIO, NGM STAFF. SOURCE: ABEL MÉNDEZ, PLANETARY HABITABILITY LABORATORY, UNIVERSITY OF PUERTO RICO AT ARECIBO

any life that might exist there. Up at the surface, comets periodically crash into Europa, depositing organic chemicals that might also serve as the building blocks of life. Particles from Jupiter's radiation belts split apart the hydrogen and oxygen that makes up the ice, forming a whole suite of molecules that living organisms could use to metabolize chemical nutrients from the vents.

The big unknown is how those chemicals could make it all the way down through the ice, which is probably 10 to 15 miles thick. The Voyager and Galileo missions made it clear, however, that the ice is riddled with cracks. Early in 2013 Hand and Caltech astronomer Mike Brown used the Keck II telescope to show that salts from Europa's ocean were likely making their way to the surface, possibly through some of those cracks. And late in 2013 another team of observers, using the Hubble Space Telescope, reported plumes of liquid water spraying from Europa's south pole. Europa's ice is evidently not impenetrable.

This makes the idea of sending a probe to orbit Europa all the more compelling. Unfortunately the orbiter mission the National Research Council evaluated in its 2011 report was deemed scientifically sound but, at $4.7 billion, too expensive. A JPL team led by Robert Pappalardo went back to the drawing board and reimagined the mission. Their Europa Clipper probe would orbit Jupiter, not Europa, which would require less propellant and save money, but it would make something like 45 flybys of the moon in an attempt to understand its surface and atmospheric chemistry, and indirectly the chemistry of the ocean.

All told, Pappalardo says, the redesigned mission should come in at under two billion dollars over its whole life span. If the mission concept goes forward, he says, "we envision a launch sometime in the early to mid 2020s." If that launch takes place aboard an Atlas V rocket, the trip to Europa will take about six years. "But it's also possible," he says, "that we could launch on the new SLS, the Space Launch System, that NASA is currently developing. It's a big rocket, and with that we could get there in 2.7 years."

The Clipper likely wouldn't be able to find life on Europa, but it could help make the case for a

Frank Drake is still looking for extraterrestrial signals—a discovery that would trump everything else.

follow-up lander that could dig into the surface, studying its chemistry the way rovers have studied Mars's. The Clipper could also scout out the best places for such a lander to set down. The next logical step after a lander—sending a probe down to explore Europa's ocean—could be a lot tougher, depending on how thick the ice is. As an alternative, mission scientists might try to reach a lake that may be entirely contained within the ice near the surface. "When that undersea explorer eventually does come to fruition," says Hand, "in evolutionary terms, it'll be like *Homo sapiens* to the *Australopithecus* we've been testing in Alaska."

The relatively crude rover Hand and his crew are testing at Sukok Lake crawls along under a foot of ice, its built-in buoyancy keeping it firmly pressed against the frozen subsurface, sensors measuring the temperature, salinity, pH, and other characteristics of the water. It doesn't look for organisms directly, however; that's currently the job of the scientists working on another aspect of Hand's project across the lake, including John Priscu of Montana State University, who last year extracted living bacteria from Lake Whillans, half a mile under the West Antarctic ice sheet. Along with geobiologist Alison Murray, of the Desert Research Institute in Reno, Nevada, and her graduate student Paula Matheus-Carnevali, Priscu is investigating what characteristics frigid environments need to make them friendly to life and what sorts of organisms actually live there.

USEFUL AS THE STUDY of extremophiles is to contemplating the nature of life beyond our planet, it can only provide terrestrial clues to an extraterrestrial mystery. Soon, however, we

will have other means to fill in missing parts of the Drake equation. NASA has approved a new planet-hunting telescope known as the Transiting Exoplanet Survey Satellite. Scheduled to launch in 2017, TESS will look for planets around our nearest neighboring stars, finding targets for astrophysicists searching planetary atmospheres for biosignature gases. The James Webb Space Telescope, scheduled for a 2018 launch, will make those searches far easier than they are today—although recent observations with the Hubble, including the discovery of clouds on a super-Earth known as GJ 1214b, make it clear that nobody is sitting around waiting for the Webb.

Some astrobiologists are even investigating a possibility that sounds more like science fiction than science. All of the focus on biosignatures and extremophiles assumes that life on other worlds, like life on Earth, will be built from complex molecules that incorporate carbon as an essential part of their structures—and use water as a solvent. One reason is that carbon and water are abundant throughout the Milky Way. Another is that we don't know how to look for noncarbon life, since we don't know what biosignatures it might leave.

"If we limit our search this way, we could fail," says Harvard's Sasselov. "We need to make an effort to understand at least some of the alternatives and what their atmospheric signatures might be." So Sasselov's group at Harvard is looking at alternate biologies that could plausibly exist on distant worlds, where, for instance, a sulfur cycle might replace the carbon cycle that dominates terrestrial biology.

In the background of all this research is the project that got astrobiology started more than half a century ago. Although he's technically retired, Frank Drake is still looking for extraterrestrial signals—a discovery that would trump everything else. Though Drake is frustrated that the funding for SETI has mostly dried up, he's excited about a brand-new project that would try to detect flashes of light, rather than radio transmissions, from alien civilizations. "It's wise to try every possible approach," he says, "because we're not very good at psyching out what extraterrestrials might actually be doing." □

Astronomer Frank Drake helped found the science of astrobiology in the 1960s by searching for radio broadcasts from alien civilizations. Now 84, he's got a new target: flashes from alien light sources. "We know how to do SETI much better these days," he says. "Our biggest challenge is coming up with the funding."

The Future of FOOD natgeofood.com

By 2050 we'll need to feed two billion more people. This special eight-month series explores how we can do that—without overwhelming the planet.

Can Africa's fertile farmland feed the planet?

Why big corporations are grabbing up land on the planet's hungriest continent.

The Next Breadbasket

By *Joel K. Bourne, Jr.*

Photographs by Robin Hammond

Sugarcane hawkers await customers on the Nacala railway in northern Mozambique, where Brazil and Japan hope to turn 35 million acres of small farms over to industrial-scale soybean production. The country has leased roughly 7 percent of its arable land—among the highest rates in Africa.

NOVASUN

Though some corporate farms have pushed small growers off their land, Bananalandia, a 3,500-acre enterprise near Maputo, has improved life for the locals. The company provides jobs for 2,800 workers and has built roads, schools, and power lines. It's also helped convert Mozambique into a banana exporter.

Sheep and goats are herded aboard a ship bound for Saudi Arabia at the Somaliland port of Berbera, a key port for Arab traders since the second century. Saudi Arabia imports 80 percent of its food, with meat consumption projected to rise this decade—good news for Somaliland's nomadic herders.

Using hand tools and draft animals, a family harvests wheat in Ethiopia's famine-prone highlands. Education has helped small farmers become more efficient, but wheat yields are still a third below the world's average. With more than a third of Ethiopians malnourished, the government is courting industrial farms to help close the gap.

FOOD

She never saw the big tractor coming. First it plowed up her banana trees. Then her corn. Then her beans, sweet potatoes, cassava. Within a few, dusty minutes the one-acre plot near Xai-Xai, Mozambique, which had fed Flora Chirime and her five children for years, was consumed by a Chinese corporation building a 50,000-acre farm, a green-and-brown checkerboard of fields covering a broad stretch of the Limpopo River Delta.

"No one even talked to me," the 45-year-old Chirime says, her voice rising with anger. "Just one day I found the tractor in my field plowing up everything. No one who lost their *machamba* has been compensated!" Local civil society groups say thousands lost their land and livelihoods to the Wanbao Africa Agricultural Development Company—all with the blessing of the Mozambican government, which has a history of neglecting local farmers' rights to land in favor of large investments. Those who managed to get jobs on the giant farm are working seven days a week with no overtime pay. A spokesman for Wanbao denied such allegations and stressed that it's training local farmers to grow rice.

Chirime's situation is hardly unique. She's just one character in the biggest story in global agriculture: the unlikely quest to turn sub-Saharan Africa, historically one of the hungriest places on the planet, into a major new breadbasket for the world. Since 2007 the near-record prices of corn, soybeans, wheat, and rice have set off a global land rush by corporate investors eager to lease or buy land in countries where acreage is cheap, governments are amenable, and property rights often ignored. Most land deals have occurred in Africa, one of the few regions on the planet that still have millions of acres of fallow land and plentiful water available for irrigation. It also has the largest "yield gap" on Earth: Although corn, wheat, and rice farmers in the U.S., China, and eurozone countries produce about three tons of grain per acre, farmers in sub-Saharan Africa average half a ton—roughly the same yield Roman farmers achieved on their wheat fields in a good year during the rule of Caesar. Despite several attempts, the green revolution's mix of fertilizers, irrigation, and high-yield seeds—which more than doubled global grain production between 1960 and 2000—never blossomed in

Mozambique

Fatima Alex

"I'm not happy. I'm angry," says Alex, who lost her small plot near Xai-Xai to a Chinese rice plantation. "That farm gave us food to eat. Now I have nothing."

Africa, thanks to the poor infrastructure, limited markets, weak governance, and fratricidal civil wars that wracked the postcolonial continent.

Many of those hurdles are now falling. Sub-Saharan Africa's economic growth has hummed along at about 5 percent a year for the past decade, besting that of the U.S. and the European Union. National debts are declining, and peaceful elections are being held with increasing frequency. More than one in three sub-Saharan Africans now own cell phones and use them for mobile banking, to run small businesses, or send money to relatives in rural areas. After 25 years of virtually no investment in African agriculture, the World Bank and donor countries have stepped up. The continent is emerging as a laboratory for testing new approaches to boosting food production. If sub-Saharan African farmers can raise their yields to even two tons of grain per acre using existing technology—a fourfold increase and still a tall order—some experts believe they could not only better feed themselves but actually export food, earning much needed cash and helping to feed the world as well.

Africa's Food Challenge

Decades ago the green revolution increased crop yields in India and other developing countries using fertilizer, irrigation, and improved seeds. But it never took root in Africa, where yields have barely risen since the 1960s. Less than 5 percent of arable land in sub-Saharan Africa is irrigated. As the continent rapidly urbanizes, an already stressed food system will lose farmers and add a staggering number of consumers. But with modern farming techniques and programs to help farmers afford them, this potential breadbasket could not only feed itself but also export a surplus.

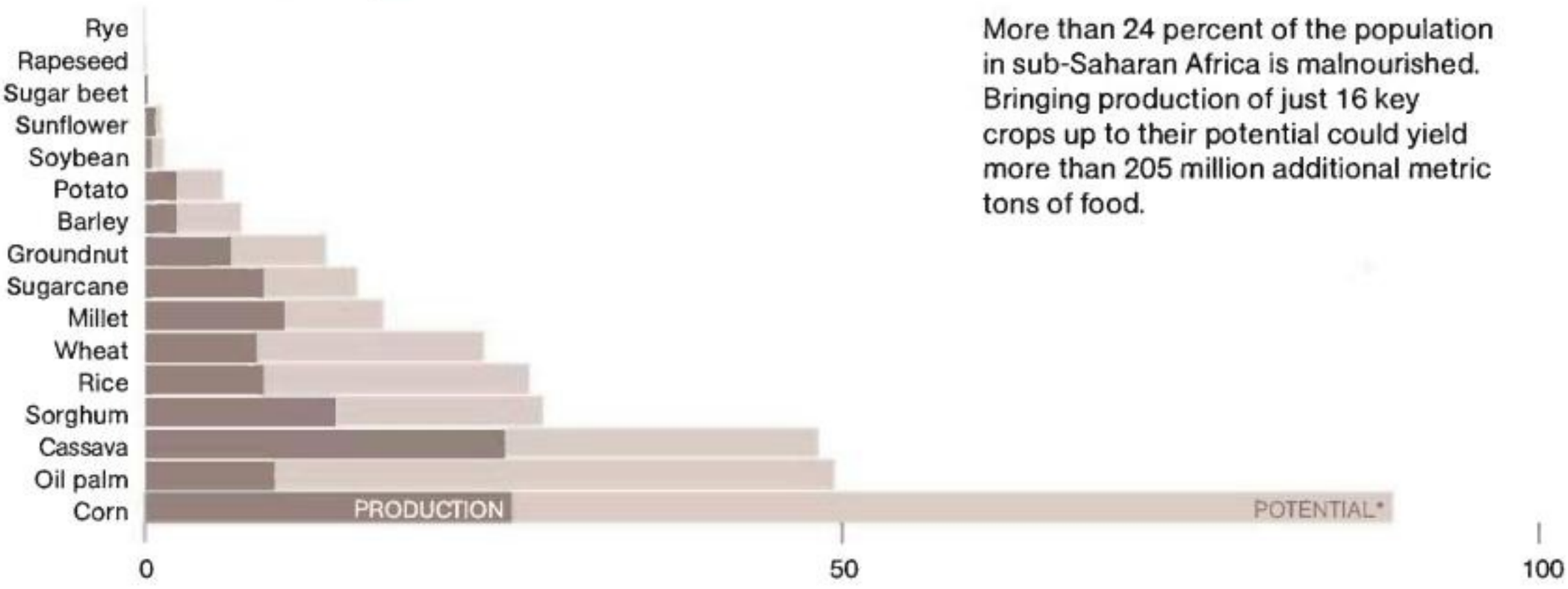
The High Cost of Fertilizer

Fertilizer prices *U.S. dollars per metric ton*

What African farmers pay for fertilizer can be more than 82 percent higher than the cost to farmers in Thailand. Factors raising the price include poor infrastructure, especially roads, and weak or corrupt governments.

Boosting the Harvest

Africa's key crops *dry weight, million metric tons*



More than 24 percent of the population in sub-Saharan Africa is malnourished. Bringing production of just 16 key crops up to their potential could yield more than 205 million additional metric tons of food.

*Potential is based on current best practices in areas with similar climates.

LOW YIELDS
Poverty, civil unrest, and lack of access to credit or markets all contribute to low yields on fertile ground.

THE YIELD GAP
Colors on the map show where harvests meet their potential or fail to. Africa's gap between potential and yield is the world's largest.

Where yields could improve

Below potential — Meets potential

Area with no crop yield

See a multilayered map of Africa's farmland on our digital editions.

HUNGRY CONTINENT
No region of the world is growing faster than sub-Saharan Africa. Today's population of 926 million may hit 2.2 billion by 2050.

Urban population over one million

10,000,000
5,000,000
1,000,000

VIRGINIA W. MASON AND JASON TREAT, NGM STAFF

SOURCES: GLOBAL LANDSCAPES INITIATIVE, UNIVERSITY OF MINNESOTA; D. I. GREGORY, INTERNATIONAL FERTILIZER DEVELOPMENT CENTER; POPULATION REFERENCE BUREAU; FAOSTAT

It's an optimistic vision, for sure. Thailand currently exports more agricultural products than all sub-Saharan countries combined, and the specter of climate change threatens to hammer Africa's yields. But the thorniest question is, Who will do the farming in Africa's future? Will it be poor farmers like Chirime working one-acre plots, who make up roughly 70 percent of the continent's labor force? Or will it be giant corporations like Wanbao, operating industrial farms modeled on those of the American Midwest?

Humanitarian groups that deal with global hunger and peasants' rights call corporate land deals neocolonialism and agri-imperialism. Yet veterans of agricultural development say the massive infusion of private cash, infrastructure, and technology that such deals may bring to poor rural areas could be a catalyst for desperately needed development—if big projects and small farmers can work together. The key, says USAID's Gregory Myers, is protecting the land rights of the people. "This could significantly reduce global poverty, and that could be the story of the century."

"IF YOU WROTE A LETTER to God and asked him for the best soil and climate conditions for farming, this is what he'd send you," says Miguel Bosch, an Argentine agronomist who manages Hoyo Hoyo, a nearly 25,000-acre corporate soybean farm in northern Mozambique. "It is a paradise for growers. I've spent many years farming in Brazil and Argentina and have never seen such soil."

Fertile land, skyrocketing demand for soybeans and rice, and a government willing to cut big land deals have put the former Portuguese colony at the center of the land rush sweeping the continent. In 2013 the nation was the third poorest on the planet, with almost half its children under five stunted by malnutrition. Recent discoveries of world-class coal and natural gas deposits in the north as well as other mining and forestry concessions are slowly changing its fortunes.

Contributing writer Joel Bourne reported on the global food crisis in 2009. Robin Hammond covered Zimbabwe in our May 2013 issue.

The rush to tap these hydrocarbons has ignited Mozambique's economy, which grew by an estimated 7 percent in 2013. Massive infrastructure projects are springing up, many financed largely by loans from nations eager to curry favor with political leaders and get in on the action. Japan is building roads and bridges. Portuguese companies are building ports and rail lines. China has already built a new airport, the parliament building, the national soccer stadium, and even the new presidential palace overlooking the broad bay in the capital, Maputo. In 2013 President Armando Guebuza spent a week visiting the new Chinese president with a ten-billion-dollar wish list of new construction projects in hand.

Little of that bounty has trickled down to the nation's 24 million citizens, more than half of whom still live on less than $1.25 a day. A return to civil unrest is the only thing that could upset the river of cash flowing into Mozambique. After riots over food prices broke out in Maputo in 2010, President Guebuza fired his agriculture minister and replaced him with Interior Minister José Pacheco, an agronomist, who has continued courting investors at conferences around the world. Of its 89 million acres of arable land, the government deems almost 85 percent "unutilized." Since 2004 some six million acres have been leased to both foreign and domestic investors for everything from forestry products to biofuels to sugarcane, roughly 7 percent of the country's arable land—among the highest rates in Africa.

Signing a deal with a ministry official in a swank Maputo hotel is the easy part. Getting a massive corporate farm up and running and turning a profit in the midst of often hostile neighbors is something else entirely. Hoyo Hoyo, located in the nation's prime soybean-growing region of Gurué, was supposed to be a shining example of the new African agriculture. Instead it became the poster child for how such deals can go wrong. In 2009 Mozambican officials leased the nearly 25,000 acres of an abandoned state farm to a Portuguese company with ties to the government. But local villagers had been growing food for their families there for years. When

This land outside Maputo provides a snapshot of Africa's agricultural choices: Will its food be produced on giant, leveled plantations like Bananalandia (at left) or on small farms, called *machambas*? "It must be a mix of big ag and small," says Dries Gouws, the sprawling banana farm's founder.

the Portuguese managers came in, they met with village leaders and promised them double the amount of land to farm elsewhere as well as a school, a clinic, and new wells.

Few of those promises were kept. The school and clinic were never built, though the company did buy an ambulance to take the sick to a hospital in Gurué, an hour's ride away. Only about 40 men got low-paying jobs as watchmen on the farm, while hundreds were displaced. Those who did receive acreage have found it to be far from home, swampy, and overgrown. Custódio Alberto is one of them. I meet the 52-year-old farmer at a threshing party just outside the Hoyo Hoyo boundary, where two dozen men from the local Roman Catholic church are beating piles of soybeans with wooden clubs. An equal number of women are winnowing the chaff with handwoven baskets. The seven-acre plot, for the moment still controlled by the church, is next to Hoyo Hoyo's wide-open fields, which stretch toward the green mountains in the distance.

"For us as small farmers, the production of this soy guarantees the family income, even enough for us to send our children to college so they can become engineers or even doctors," Alberto says. "Fields are fundamental for us. No fields, no life."

The displaced villagers, who survived 16 years of war, are poor but far from powerless. Soon after the Portuguese got the lease to Hoyo Hoyo, which

A worker waters oil palm seedlings to be planted on part of a 543,600-acre lease in Liberia that will produce cooking oil. Government leaders hope the 35,000 jobs promised by Malaysian palm oil giant Sime Darby will help calm tensions in the war-torn land.

A Chinese chicken farmer haggles with his customers in Lusaka, Zambia. Like many foreign-owned food operations in Africa, his company doesn't ship its chickens back home but sells them to locals and the country's 20,000 Chinese. Overall Africa is home to some two million Chinese.

means "welcome" in the local language, the farm began having trouble with its equipment. John Deere tractors imported from the United States mysteriously failed to start. I ask a farmer working nearby what the problem was.

"I don't know how it happens," he said with a knowing smile. "Maybe African magic."

THE CONFLICT OVER Hoyo Hoyo pales in comparison with what's coming down the road. In 2009 the government signed an agreement with Brazil and Japan to develop an agricultural megaproject dubbed ProSavana, which would make almost 35 million acres of northern Mozambique available for industrial-scale soybean production, possibly the largest such land deal ever reported. The plan is inspired by a Japanese-Brazilian project that transformed Brazil's *cerrado* grasslands into one of the largest soy-exporting regions in the world, with the bulk of its yield going to feed Europe's and China's livestock. The North Carolina–size corridor would be dotted here and there with modern, 25,000-acre farms run by Brazilian agribusinesses and with technical centers to educate local farmers on how to boost yields of cassava, beans, vegetables, as well as soy—or so the initial vision went. But when a group of Brazilian farmers toured the region in 2013, they had a rude awakening.

"They saw good lands, but everywhere was a community," says Anacleto Saint Mart, who works with farmers in the region for the U.S. nonprofit TechnoServe. "They were seeing a reality very different from what they were told in Brazil." Development experts who've pored over maps of the area say most of it is already leased for mining or logging, is protected as wildlife reserves, or is already being cultivated by local farmers. Only about 2.2 million acres are currently unutilized, and those are the worst lands for farming.

"When you look at ProSavana, who is winning?" asks Devlin Kuyek of GRAIN, the nonprofit that first focused the world's attention on corporate investments in farmland. "The land is currently worked by small farmers, and [yet] the government is placing it in the hands of corporations. I'm sure there are some companies with good intentions. But they're still profiting from low wages and low land prices. Industrial agriculture will just lead to more exploitation."

With the right policies, small farmers can be extremely productive, Kuyek says, pointing to the rice farmers of Vietnam or the small dairy farmers in Kenya, who supply more than 70 percent of the nation's milk. Simply providing women—who make up the majority of African farmers—the same access to land, credit, and fertilizer as men could boost food production by as much as 30 percent. The government of Mozambique doesn't see it that way. Though food production by small farmers has improved over the past few years, 37 percent of the population is undernourished, and the country's southern region is plagued by droughts and floods. Despite its mineral wealth, Mozambique remains one of the hungriest nations in the world. The government thinks bigger farms are the answer.

"I look at ProSavana along with the Zambezi Valley region as the food store of the country," says Raimundo Matule, the national director of economics at the Ministry of Agriculture. "I don't envision huge farms like in Brazil, but more medium-size producers of three to ten hectares [7 to 25 acres]. The Brazilians have knowledge, technology, and equipment that we can adapt and transfer to medium-size farms. If ProSavana doesn't contribute to better food security, then it will not have government support."

A FEW MILES down a washboard dirt road from Hoyo Hoyo, a soybean farm run by a retired schoolteacher is an example of a productive middle path. Armando Afonso Catxava began growing vegetables in his spare time on a small plot of land and over the years has cobbled together about 64 acres. He now grows soybeans as an "outgrower" under contract with a new company called African Century Agriculture, which provides him with seeds and mechanical weeding. In return he sells his soybeans to the company at an agreed-on price, minus the cost of the services provided. So far both have profited from the arrangement.

"I think middle-size farms are the secret,"

Ethiopia

Greda Telila

On his five-acre farm Telila grows stalks of sorghum. A subsistence farmer whose land is prone to flooding, he struggles to feed his 12 children.

Catxava says. "Big farms take too much area, and there is nowhere for people to live. If everybody had five hectares [12 acres] of soy, they would make money and not lose their land." Outgrower arrangements have been successful with poultry and high-value crops like tobacco and even organic baby corn grown for export to Europe. Now Mozambique's farmers are starting to raise soybeans for feed to supply the booming chicken industry.

Rachel Grobbelaar is a tall, tough Zimbabwean who left a good job in London's financial district to run African Century, which works with more than 900 outgrowers—a mix of smallholders and medium-size growers—on nearly 2,500 acres. Farmers each get seven visits a season from the company's extension agents, who teach them the basics of conservation agriculture and the use of inexpensive seed treatments, instead of expensive fertilizer, to boost yields.

"I was visiting one of our small farmers up on the mountain yesterday, and he grew 2.4 tons per hectare [one ton per acre]," Grobbelaar says, referring to last year's harvest—more than double

Ajiem Ogalla, 11, scavenges for *awieo*, an edible shrub, amid corn planted by the Indian firm Karuturi Global, which holds part of a large agricultural lease in Ethiopia's remote Gambela region. After displacing villagers and cutting down native forests, the company is deeply in debt and struggling to avoid bankruptcy.

the average yield. "He couldn't believe it. He made 37,000 meticaies [about $1,200] profit. That's a lot. I'm very supportive of the outgrower model in Africa. Commercial farms may give them a job, but it takes away their land and typically pays them bare-minimum salaries. I honestly believe we can increase production this way."

When done right, larger-scale farms can benefit locals too. Dries Gouws, a former surgeon in Zambia, planted 30 acres of banana trees on a bankrupt citrus farm outside of Maputo 14 years ago. He slowly grew the operation into what he now calls Bananalandia. At 3,500 acres, it's the largest banana farm in Mozambique and one of the nation's largest employers, with 2,800 year-round workers. During that time Gouws's farm helped turn Mozambique from a banana importer into a banana exporter. As the farm grew, Gouws paved roads, built a school and a clinic, dug wells, and ran 34 miles of electrical lines that not only power his irrigation but also supply the surrounding villages where his employees live. His lowest paid workers make 10 percent more than minimum wage; his tractor drivers and plantation managers make more than double that.

Gouws believes in a mix of big and little farms, with small farmers raising cattle and tending plots of land as a safety net and source of pride, and big farms like his bringing in roads, power, and infrastructure that the government does not provide. Big farms supply employment for some; other people make it on their own. The key to corporate farms winning over local communities, he says, is simple: Keep your word.

"I built this power line for the village," Gouws says, as we follow a wire along a red-dirt path toward a cluster of huts amid the banana fields. "I've never been asked to do it or expected to do it. But at some point, not to get too philosophical about it, we want to make the world a better place, don't we? It can't just be about the money."

Yet make no mistake, money—not some noble idea of feeding the world—is driving the land rush in Africa. A recent conference for agricultural investors in New York drew some 800 financial leaders from around the globe who manage nearly three trillion dollars in investments. These included giant pension funds, life insurance companies, hedge funds, private equity funds, and sovereign-wealth funds, which currently have about 5 percent of their combined assets allocated to investments in agriculture. That number is expected to triple over the next decade. Such a massive infusion of private cash, technology, and infrastructure is exactly what global agriculture needs, according to FAO experts, who estimate we'll need to invest $83 billion a year in agriculture in developing countries to feed two billion more people by 2050.

The key is leveraging that investment to yield benefits for all, ensuring secure land rights, thriving markets, and increased productivity on all farms, big and small. "If we could do that, we'd have a triple win," says Darryl Vhugen, a lawyer with Landesa, a Seattle-based nonprofit that helps poor farmers in developing countries defend their land rights. "Investors benefit, local communities benefit, and nations benefit from jobs, infrastructure, food security. That's gold."

ON A LONG ROAD in the heart of the proposed ProSavana project, I stop at a mud-brick hut to talk with Costa Ernesto, a 35-year-old farmer, and his wife, Cecilia Luis. They have never heard of ProSavana. They are simply trying to feed their family on two and a half acres of corn, and selling bamboo poles for thatched roofs on the side. Their five children range in age from six months to 11 years. The eldest, a shy girl named Esvalta, is pounding corn with a wooden pestle

The Future of Food

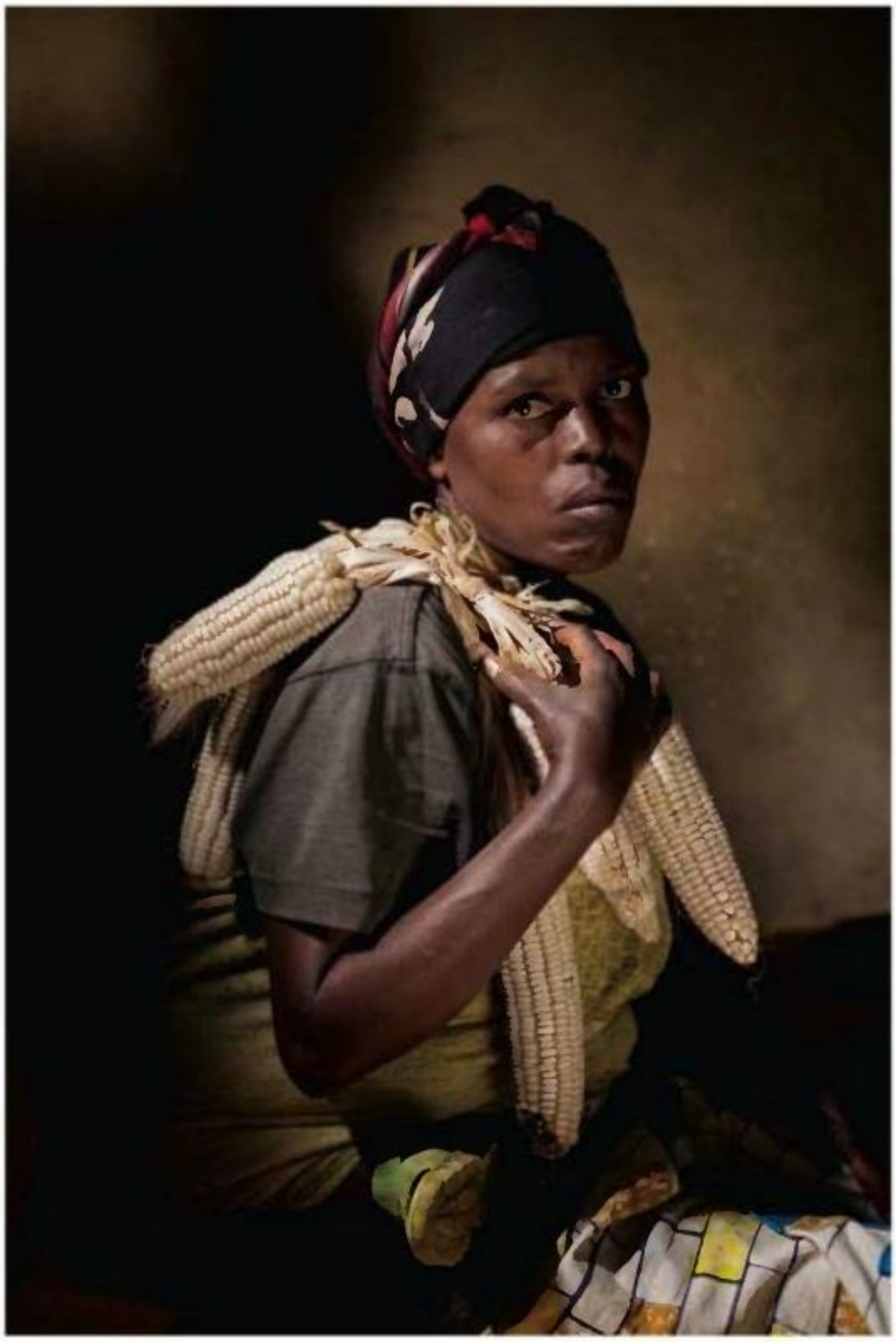
COMING IN AUGUST

Millions of working Americans are going hungry.

ON THE WEB

Join the conversation at *natgeofood.com* and get daily food news, videos, informed blogs, interactive graphics, bonus photos, and food facts of the day.

The magazine thanks The Rockefeller Foundation and members of the National Geographic Society for their generous support of this series of articles.



Rwanda

Marie Mukarukaka

"Before, I grew only food for my family, and it would last two weeks," says Mukarukaka. After receiving a seed and fertilizer loan from the One Acre Fund, she has boosted her yields and is now raising livestock too.

as tall as she is, just as her mother and grandmother and great-grandmother did before her. My guide, who has worked in agricultural development for 20 years, says the children and parents appear to be stunted from malnutrition. I ask Ernesto if he has grown enough corn to eat that year. "Yes," he says proudly. After some prodding, Cecilia adds: "When we keep ahead of weeding, we produce enough for the whole year."

Two other men walk up during the conversation, and I ask if they would give up their small farms for a job on a big farm. Given their ragged clothing, their swollen bellies, their sod houses, their obvious poverty, the question seems almost unfair. Yes, they say, without the slightest hesitation.

"I have been praying that something like this would happen," the oldest of the three men replies. "Because I really need a job."

Whether Mozambique's future farmers will look more like industrial farmers in Iowa or the small but productive rice farmers of Vietnam remains to be seen. But all sides agree on one thing: The status quo is unacceptable. □

A girl tends goats in the mountains near Shiikh, Somaliland. Though big farms make headlines, small farmers still produce most of the food in Africa. Both are crucial for the continent to be able to feed its own growing population—much less the rest of the world.

FOOD

The Future of Food
natgeofood.com

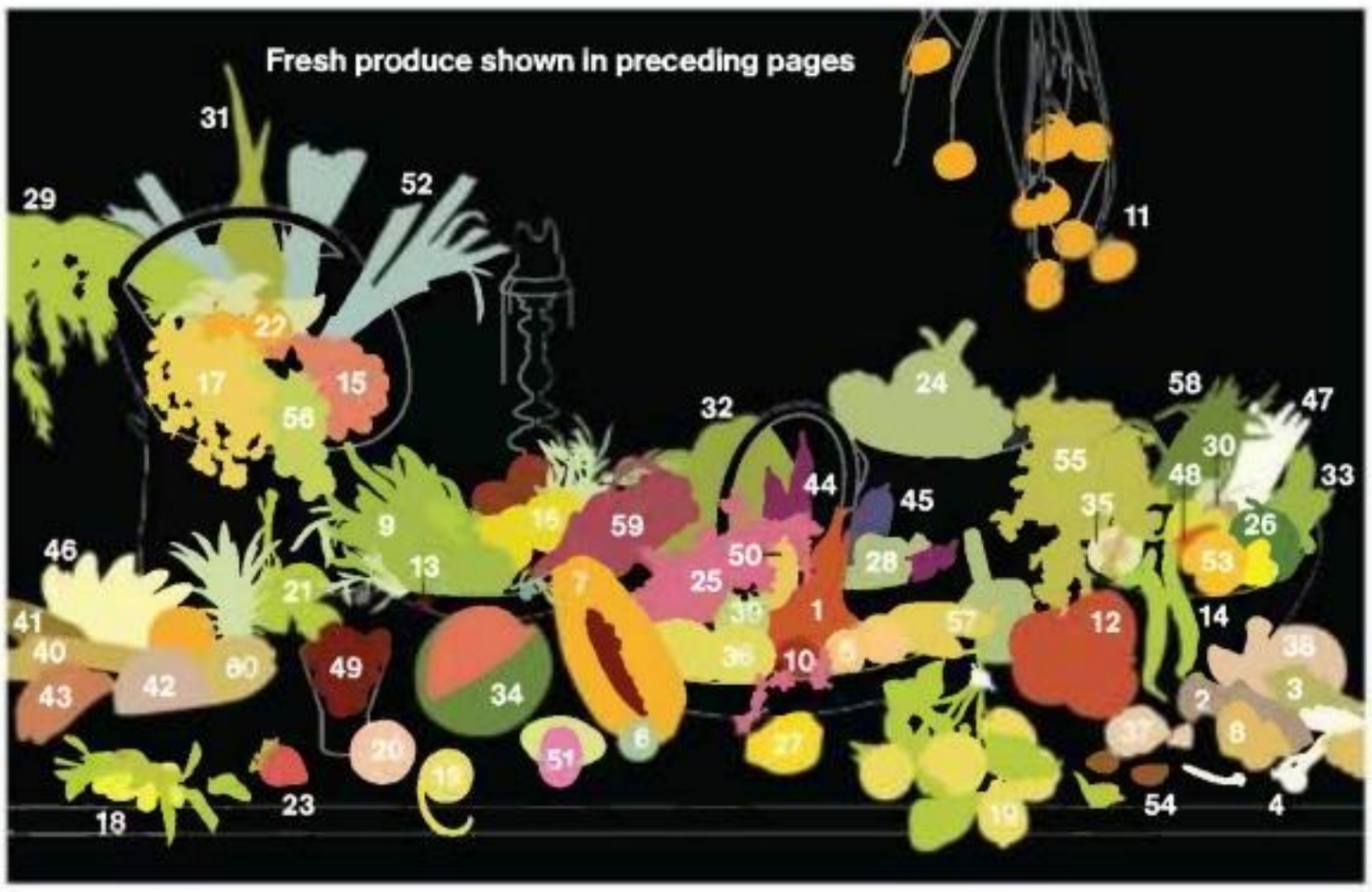
A Moveable Feast

This isn't a still life from 17th-century Europe. It's fresh produce from four upscale markets in Manhattan. Eating locally and reducing carbon footprints may be in, but these fruits and vegetables made big trips to the Big Apple—in some cases covering nearly 9,000 miles. In fact, in the United States, produce imports have increased significantly since 1980. Amit Ratanshi, a seller at a Bronx distributor, says New York chefs and shoppers "want to know where their food is coming from." That can mean a farm down the road, across the country, or—if it's exotic goods—half a world away.

PHOTO: PAULETTE TAVORMINA

FOOD

Behind the Moveable Feast



Big-city produce comes from near and far. Dartmouth geographer Susanne Freidberg says that's nothing new. In the 19th century, before cold storage, New Yorkers got Christmas citrus from Italy. Modern global trade grew as vehicles and cargo did. Today food moves quickly, thanks to improved transport logistics.

DISTANCE (MILES) AND TIME TO NEW YORK CITY

1. Dragon fruit
8,970, 1-2 days

2. King oyster mushrooms
7,420, 1-2 days

3. Enoki mushrooms
6,920, 1-2 days

4. White hon-shimejis
6,760, 1-2 days

5. Apricots
8,845, 1-2 days

6. Kiwi
8,845, 1-2 days

7. Papaya
5,330, 7-10 days

8. Chanterelles
2,465, 1-2 days

9. Buddha's hands
2,665, 2 days

10. Passion fruit
2,890, 3-4 days

PRODUCE MILEAGE*

The total distance traveled by all the food items combined is about 223,875 miles. That's enough to travel around the Earth roughly nine times.

Average distance traveled for all of the items: **3,731 miles**

Average time: **4-5 days**

HOW THEY TRAVELED

22 by truck

21 by plane

17 by boat

ORIGINS

32 international

28 domestic

*Distances, routes, and locations are estimates; only primary forms of transportation shown

ART BY JOHN GRIMWADE AND HAISAM HUSSEIN; ALEXANDER STEGMAIER, NGM STAFF; MEG ROOSEVELT

SOURCES: EATALY/BALDOR SPECIALTY FOODS; MANHATTAN FRUIT EXCHANGE; WHOLE FOODS; G. PAGE WHOLESALE FLOWERS

11. Persimmons
2,665, 2 days

12. Pomegranates
2,665, 2 days

13. Olive
2,660, 2 days

14. Italian hot peppers
2,940, 5 days

15. Red grapes
2,815, 5 days

16. Quinces
2,915, 3-4 days

17. Dates
2,635, 2 days

18. Kumquats
2,635, 2 days

19. Lemons
2,635, 2 days

20. Pink variegated lemon
2,940, 5 days

21. Limes
2,635, 2 days

22. Oranges
2,635, 2 days

23. Strawberry
2,940, 4 days

24. Artichokes
2,995, 3-4 days

25. Pepperberries
2,740, 2 days

26. Green pepper
2,800, 3-4 days

27. Star fruit
2,760, 3-4 days

28. Artichokes
2,995, 5-6 days

29. Baby fennel
2,800, 3-4 days

30. Cipollini onions
2,050, 3-4 days

31. Aloe vera
2,685, 3-4 days

32. Cactus
2,685, 3-4 days

33. Chili peppers
2,685, 3-4 days

34. Watermelon
3,470, 5-7 days

35. Avocado
3,670, 5-6 days

36. Chayotes
4,000, 3-4 days

37. Shiitake mushrooms
135, 1 day

38. Portobello mushrooms
135, 1 day

39. Guava
1,220, 2-3 days

40. Sugarcane
1,220, 2-3 days

41. Yucca
2,590, 7 days

42. Coconut
2,590, 7 days

43. Red bananas
2,460, 7 days

44. Indian eggplant
2,040, 5-7 days

45. Graffiti eggplant
2,040, 5-7 days

46. Baby bananas
3,135, 7 days

47. White asparagus
3,645, 1-2 days

48. Dried chilies
5,740, 7-10 days

49. Cherries
5,740, 7-10 days

50. Bosc pear
6,775, 10 days

51. Prickly pear
5,300, 10 days

52. Leeks
3,820, 10-14 days

53. Orange pepper
3,820, 10-14 days

54. Chestnuts
4,815, 10-14 days

55. Frisée
4,055, 1-2 days

56. Green grapes
4,815, 10-14 days

57. Abate Fetel pears
4,825, 10-12 days

58. Puntarella
4,415, 1-2 days

59. Treviso radicchio
4,415, 1-2 days

60. Baby pineapple
8,970, 12 days

THE WELLS OF MEMORY

OUT OF EDEN WALK
Part two

One of the first travelers in a century to walk through the Hejaz desert of Saudi Arabia, PAUL SALOPEK encounters a fabled past of caravans and pilgrims, of empires come and gone.

A pre-Islamic people, Nabataeans carved palatial tombs at Madain Salih.

As an armed guard keeps watch, Governor Mosaad Al-Saleem (at far right) entertains guests during a regatta near the Red Sea port city of Yanbu al Bahr, much of it built in the 1970s.

PHOTOGRAPHS BY JOHN STANMEYER

THERE ARE THOUSANDS OF WELLS IN THE OLD HEJAZ. WE WALK TO THEM.

Sometimes their water is sweet. More often it is salt. It matters little. These wells, which pock the long-disused caravan trails of Arabia, are monuments to human survival. Each concentrates a fine distillation of the landscape. And the same applies to the people who drink from them. In the Hejaz—the fabled realm of a vanished kingdom of the Hashemites, who once ruled the Red Sea coast of Saudi Arabia—there are bustling wells and lonesome wells. There are wells whose waters convey the chemistry of sadness or joy. Each represents a cosmos in a bucket. We take our bearings off them.

Wadi Wasit is a well of forgetting.

We reach it on a fiery day in August. We are halfway through a more than 700-mile foot journey, perhaps the first made in generations, from Jeddah to Jordan. We rest in the dendrites of gray shade thrown by the well's two thorn trees. Here we meet the running man.

He arrives in a pickup truck. Portly, mustachioed, a Bedouin camel herder, he is friendly, curious, talkative, jittery. He mistakes us for treasure seekers. (Why else walk through the scorching desert?) He has come to sell artifacts.

"Look at this!" he says. He displays a tin ring. The iron scabbard of a sword. A well-rubbed coin.

How old are these things?

The running man doesn't know. "*Kadim jidn,*" he says: Very old. He shrugs.

The Hejaz—a crossroads where Arabia, Africa, and Asia meet, and long tied by trade to Europe—is one of the most storied corners of the ancient world. It has seen millennia of wanderers. Stone Age people hunted and fished their way north out of Africa through vanished savannas. People from some of humankind's first civilizations—Assyrians, Egyptians, and Nabataeans—roamed through here, trading slaves for incense and gold. Romans invaded the Hejaz. (Thousands of the legionaries died of disease and thirst.) Islam was born here, in the dark volcanic hills of Mecca and Medina. Pilgrims from Morocco or Constantinople probably drank from the well in Wadi Wasit. Lawrence of Arabia may have gulped its water too. Nobody knows. Kadim jidn.

"Take it!" the running man says. He shoves his orphan finds at us. "Take it for free!" But we decline to buy his curiosities.

Packing our two camels to leave, we spot him once again. He is running now—sprinting around the well. He has removed his white robe. And he

Moses Spring near Maqnah is named for the prophet believed by the faithful—
Jewish, Christian, and Muslim—to have parted the Red Sea to lead the Israelites out of Egypt.
Photographer John Stanmeyer made the retro image with a smartphone camera app.

is running through the desert in his underwear, circling the well under the ruthless sun. He runs with abandon. Ali al Harbi, my translator, takes a photograph. Awad Omran, our camel handler, guffaws. But I cannot laugh. He is not mad, the running man. Or drugged. Or playing some joke. He is lost, I think. As we all are when we abandon history. We don't know where to go. There is an abundance of pasts in the Hejaz. But I have never been to a place more memory-less.

A SMALL, BOTTOMLESS WELL in the Hejaz: a white porcelain cup.

It holds dark, rich coffee. It sits atop a polished wooden table inside an elegant mansion in the port of Jeddah. Three articulate Hejazi women refill the cup endlessly. They take turns talking, wishing to correct misperceptions about Saudi Arabia: that the kingdom is a homogenized society, a culture flattened by its famously austere brand of Islam, a nation rendered dull by escapist consumerism and by petrodollars. No.

Saudi Arabia, they say, is a rich human mosaic. It enfolds many distinctive regions and cultures: a Shiite east, a Yemeni south, a Levantine north, and a tribal Bedouin stronghold in the center—the puritanical redoubt of the Najdis, home of the ruling dynasty, the House of Saud. The women insist, moreover, that no region in Saudi Arabia remains more independent, more

IN THE FOOTSTEPS OF PILGRIMS

Surrounded by the ghosts of travelers who came before him, author Salopek camps amid 2,000-year-old Nabataean tombs at Madain Salih. On the second leg of his Out of Eden Walk project, a seven-year quest to trace the spread of humans across the world, Salopek spent 199 days walking 780 miles through the old Hejaz kingdom of Saudi Arabia, a region rarely traversed on foot by outsiders. Much of his route followed the "pilgrim roads," the now faint trails to the holy city of Mecca.

proud, than the realm that has guarded the holy cities of Mecca and Medina since the tenth century—the vanished kingdom of the Hejaz. Fully independent by the end of World War I, the Hejaz was annexed by the Al Saud dynasty only in 1925. It remains a place of contradictions, of complexity, of tensions between religion and geography. On the one hand: a sacred landscape, its holy cities long forbidden to non-believers. On the other: the most cosmopolitan and liberal corner of Saudi Arabia, a melting pot, an entrepôt and nexus of migration, brightly checkered with influences from Asia, Africa, the Levant, and a hundred other places—the California of Saudi Arabia.

Laila Abduljawad, a cultural preservationist: "The Hejaz has attracted pilgrims from every corner of the Islamic world. How could this not rub off? Our main dish is Bukhari rice from Central Asia! Our folk textiles are Indian! Our accents are Egyptian! We are more open to the world than the people from the center."

Salma Alireza, a traditional embroiderer: "The traditional dress for women in the Hejaz was not the abaya"—the severe black robe imposed by the ruling Najdis. "Women here used to wear bright red and blue dresses in public. That was traditional. But life changed in the 1960s. The oil money poured in. We modernized too fast. We lost so much in 50 years!"

Rabya Alfadl, a young marketing consultant: "Is the Hejaz still different? Take a look around."

And it's true. The women sit at the table unveiled. They wear casual Western clothing: blouses and trousers. (Such a meeting would be difficult to arrange in the Saudi capital, Riyadh, where gender segregation and tribal ways remain so strict that a man will not utter his mother's name in public.) The house where we chat is sleekly designed, chic, minimalist, global in decor. And outside, in Jeddah's streets, there are art galleries, cafés, promenades, museums—the cultural hub of Saudi Arabia.

"A sense of cultural identity has persisted in the Hejaz for a thousand years. It developed its own music, its cuisine, its own folktales," Abduljawad tells me. She turns her cup in her hands. "We are taking our first baby steps to rescue a small part of this."

These women are daughters of a feminine city. Arab folk tradition holds that the biblical Eve was buried in Jeddah, now a modern, sprawling, industrial port. Eve's tomb—200 yards long, shaped like a reclining figure—was crowned by an "ancient and lofty dome," according to the Moorish traveler Ibn Jubayr. It is gone, marked today by a barren concrete cemetery. Wahhabi clerics, who abhor shrines as idolatrous, likely razed it nearly a century ago. But again, no one can remember.

MAPS: RYAN MORRIS, NGM STAFF

For centuries a well at the Al Bad oasis nourished camel caravans and religious travelers. It is now a dry hole. Folklore says that Moses watered his sheep here

Water is precious in Duba, where a Bangladeshi attendant fills jugs for drive-by customers. The water is trucked from wells as far as 100 miles away and then purified.

MORE THAN 300 MILES NORTH of Jeddah, near a dry well called Al Amarah, we stop walking. We look up from our tired feet. A car approaches across a plain of glistening salt. It is a Toyota HiLux, the iron camel of the modern Bedouin.

This is an event. Traversing western Saudi Arabia on foot today is lonelier than it was one or two generations ago when the black tents of Bedouin were still pegged to the brittle hide of the desert. The famous nomads of the Hejaz—the Balawi, the Harb, the Juhayna—have resettled in towns, in suburbs, in offices, in army barracks. Modern Saudi Arabia is heavily urbanized (matching the United States in this respect).

Yet a few diehards remain.

One steps from the truck. He is a graybeard in a stained gray *thobe*, the classic robe of Saudi men. He brings us a gift. "It is our way," says the old man, who calls himself Abu Saleh. He sweeps a callused hand at the surrounding desert. "We welcome all travelers."

No other soul is visible on the horizon. Abu Saleh leaves us with a simple goodbye. His gift: a small well of kindness—a dented steel bowl full of camel's milk.

BUILT OF NECESSITY, the wells in the old Hejaz have faded, softened, eroded into objects of beauty and contemplation.

The earliest of these watering stations were established, precisely one day's walk apart, by the Caliph Umar in A.D. 638. "A traveler is the person worthiest of receiving protection," he declared, before pioneering the most sophisticated rest-stop system in the ancient world: waypoints on the pilgrims' trails to Mecca serviced by forts, cisterns, guesthouses, date groves, hospitals, canals, even distance markers.

We trudge the same trails—ribbons of desert burnished by countless shuffling camels, by numberless sandaled feet. Scholars from Timbuktu drank from these wells. So did merchants from Spain seeking frankincense. So did sun-boiled 19th-century European explorers who rambled the Hejaz disguised as pilgrims. One who didn't pose was a blustery Englishman named Charles M. Doughty. He announced himself to everyone as a Christian, an infidel, and walked with a knife up his sleeve. (Of one caravan swollen with 10,000 animals and 6,000 people, he wrote: "The length of the slow-footed multitude of men and cattle is near two miles, and the width some hundred yards in the open plains.")

SCHOLARS FROM TIMBUKTU DRANK FROM THESE WELLS.
SO DID MERCHANTS FROM SPAIN SEEKING FRANKINCENSE.
SO DID SUN-BOILED EUROPEAN EXPLORERS.

North of the city of Al Wajh we unpack our two camels at a well, utterly ignored by the speeding traffic of a superhighway. This well, called Al Antar, was rendered obsolete a century ago by steamships. It is made absurd today by the pilgrims hurtling overhead in Boeing 777s. I bend over the well's lip. A damp air breathes up from its darkness, cooling my cheeks. I hear from somewhere far below the calls of startled songbirds. I think: Arabia is like the American West. It is a landscape of terrible absences.

IF THE HEJAZ STILL INSPIRES romance in the non-Muslim world, it is due to its long caravan of foreign chroniclers.

There is the 19th-century Swiss polymath Johann Ludwig Burckhardt, who traveled to the religious core of Islam as a pauper—a "reduced Egyptian gentleman"—and never made it

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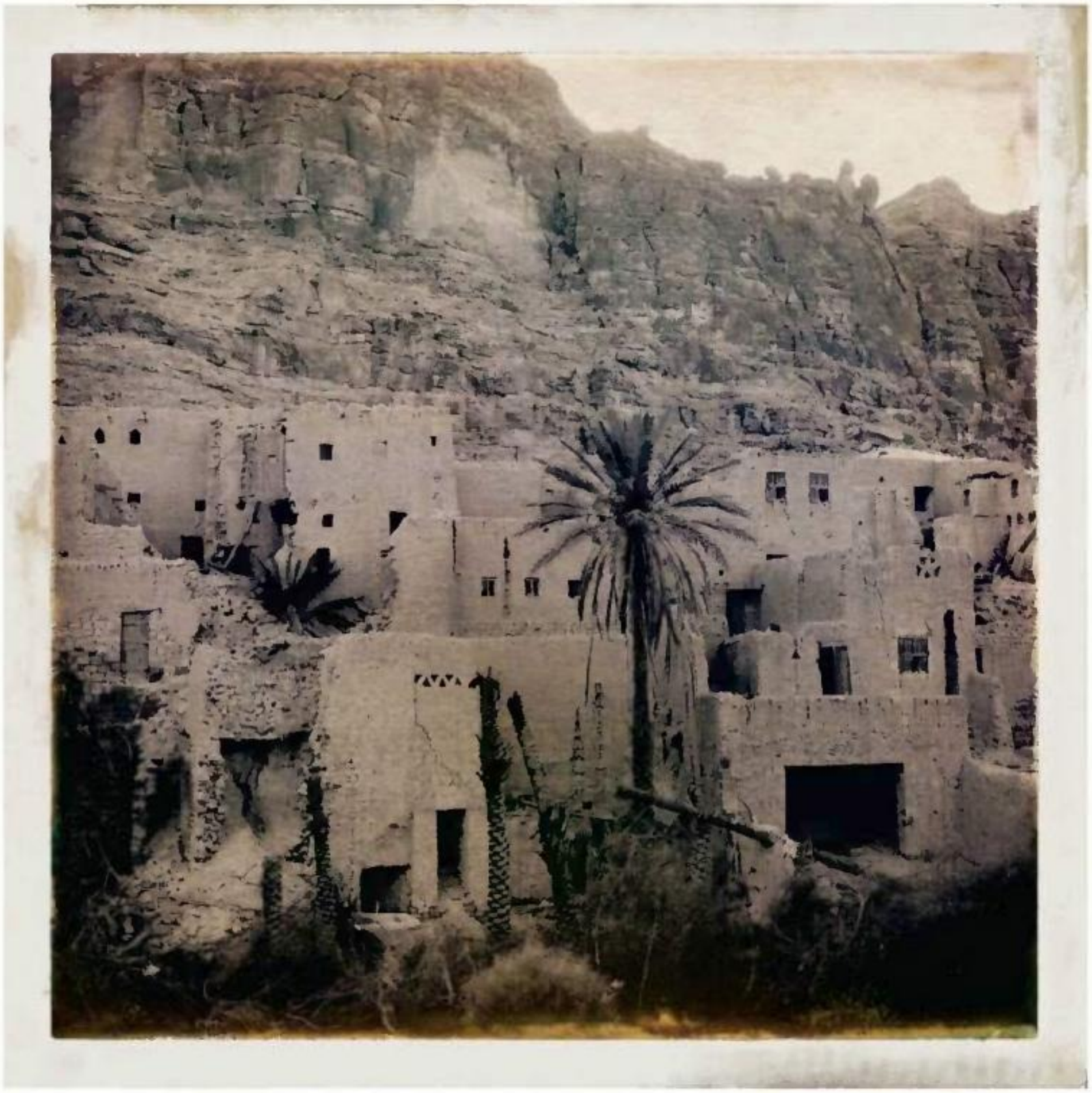
To read National Geographic Fellow Paul Salopek's dispatches from the trail and post your comments, visit nationalgeographic.com/edenwalk. *Follow on* Twitter: @outofedenwalk. *John Stanmeyer won World Press Photo of the Year 2013 for his image of migrants holding up cell phones at night in part one of "Out of Eden," December 2013.*



For centuries the stone and mud-brick houses of Al Ula hosted religious travelers and traders carrying spices and incense. In the 1970s Saudi authorities moved residents of the old quarter to a brand-new city next door.

home. (He died of dysentery and was buried with Muslim rites in Cairo.) There is the brilliant and pompous Englishman Richard Francis Burton, who, if he can be believed, actually touched the Kaaba, the holiest of holies—a massive cube of volcanic stone in Mecca toward which all Muslims must pray. These Europeans witnessed a world locked in time. They found Red Sea towns built of shining white coral blocks, their arched doors and window shutters painted sea green and dazzling nomad blue. They passed through walled cities whose tall gates creaked shut at dusk. They galloped camels between fortified oases with wild-haired men, the Bedouin, whom they found harshly admirable. (Burton: "We had another fight before we got to Mecca, and a splendid camel in front of me was shot through the heart.") This literary Hejaz, if it ever truly existed, has long since disappeared under American-style suburbs and strip malls. Yet outside the old pilgrim's port of Al Wajh, we stumble upon the ghost of one of the most famous of these Orientalists.

Workmen are cleaning out a well.

The well lies within the high rock walls of Al Zurayb fortress, built 400 years ago by the Ottomans. The laborers haul up old explosives: cannon shells that look like rusted pineapples. The ordnance was chucked down the well in panic, probably in January 1917. At that time a camel-back Arab army was approaching fast. The tribes

At her Jeddah home, single mom Yasmin Gahtani dresses casually to help her boys with homework. In public, even in one of the most liberal Saudi cities, she wears an abaya, or robe.

of the Hejaz had risen against their German-allied Ottoman overlords. And the foreigner who had stoked the revolt—he was barely five feet five inches tall but possessed a masochistic hardness—whooped along with the attackers. Of the Arab cavalry he wrote: "They wore rusty-red tunics henna-dyed, under black cloaks, and carried swords. Each had a slave crouched behind him on the crupper [of the camel] to help him with rifle and dagger in the fight, and to watch his camel and cook for him on the road."

Thomas Edward Lawrence, more famous as Lawrence of Arabia, is one of our first postmodern heroes: a compromised superman. The young British intelligence officer and Oxford medievalist yearned, subversively, to bring liberty to an Arab world that was then staggering under the corrupt yoke of the Ottoman Turks. Yet he was tormented by the knowledge that the Hejazis who fought alongside him would be betrayed by the European colonial powers that carved up the Middle East after World War I.

"Lorens al Arab," I tell the workmen at the fort. I point to the live shells.

The name means nothing to them. Lawrence is virtually forgotten in Saudi Arabia. He backed the wrong dynasty after the war. His champion, Faisal, the moderate Hashemite prince of the Hejaz, lost a power struggle to the fierce tribes of the interior led by the peninsula's future king, Ibn Saud.

"They were a people of spasms, of upheavals, of ideas, the race of the individual genius," Lawrence wrote of his comrades in the Hejaz. "The desert Arab found no joy like the joy of voluntarily holding back. He found luxury in abnegation, renunciation, self restraint. He made nakedness of the mind as sensuous as nakedness of the body. He saved his own soul, perhaps, and without danger, but in a hard selfishness."

This is what happens when you peer down wells in the Hejaz. You glimpse your own reflection. Lawrence, an ascetic of empire, was describing himself.

WELLS OF PIETY: plastic cups of water arranged by the thousands across a stone courtyard in Medina.

It is Ramadan, the fasting month. The holiest month of the Muslim lunar calendar. Just outside Al Masjid al Nabawi, the burial mosque of the Prophet Muhammad, the second holiest site in Islam, at least 60,000 faithful are gathered at sunset to break the day's hunger.

They come from all quadrants of the Earth. I see Indians and Africans. I hear French. I am not Muslim. But I have been fasting all month out of respect. Across from me a big pilgrim from Afghanistan—a red-haired Nuristani—kneels in front of one of the prepackaged meals distributed daily at the site. He hands me his orange. I give him mine. We exchange our food like this several times, laughing. On the loudspeakers an imam sings the crowd into prayer. They pray. And beneath a fading yellow sky, we eat in tender silence.

LAWRENCE OF ARABIA WAS TORMENTED BY THE KNOWLEDGE THAT THE HEJAZIS WOULD BE BETRAYED BY THE EUROPEAN POWERS.

STRANGE NEW WELLS on the roads of the Hejaz: machines humming in the desert.

Their fitted aluminum surfaces shine under the sun. Hallucinations of metal. Of rubber and plastic. They are outdoor electric coolers. They dispense water so icy it numbs the mouth. We encounter hundreds of these mechanical shrines, called *asbila:* public water fountains commissioned by the pious to earn virtue in the eyes of Allah. One day their rusted parts, jutting from the shifting dunes, will puzzle archaeologists. How can any society afford to chill a cup of water in a barrens as gigantic and remote as the Hejaz? It seems impossible. Mystifying. Yet the

A Styrofoam replica of the Kaaba, the "sacred house" in the center of Mecca's Grand Mosque, serves as teaching tool in an arts center at a Jeddah mall. Parents bring children to instruct them in hajj pilgrimage rituals, like circling the Kaaba seven times.

asbila from which we gratefully fill our canteens exist because of other wells—ones drilled in the distant oil fields of eastern Saudi Arabia.

"We've traded away our past for wealth," laments Ibrahim, a water engineer in the port of Al Wajh. "My grandfather's 200-year-old coral-block home? Bulldozed. The docks where dhows from Eritrea brought in camels? Gone. Our city's stone lighthouse that used to be seen from 20 kilometers at sea? Rubble. Nobody cares. It's all old stuff. It has no economic value."

Some Hejazis blame Saudi Arabia's ultraconservative version of Islam for much of the erasure of their past. In recent years, for example, urban historians have decried the demolition of the old quarters of Mecca and Medina, including the flattening of ancient structures associated with Muhammad himself. Officially this was done to provide services for the two million or more pilgrims who swell the cities on hajj. But religious authorities have frequently blessed the destruction of cultural sites. Wahhabis emphasize that all the past before Islam is *jahiliyya:* a time of ignorance. And they fear that even the preservation of Islamic sites may lead to the worship of objects, and not God—thus promoting idolatry, or *shirk.*

It is worth noting that the loudest laments for the disappearing heritage of the old Hejaz come from Muslims outside Saudi Arabia. "It is difficult to get young Saudis involved in their

Weekend nomads, SUV-driving camel owners from Yanbu al Bahr pray at a deluxe desert camp. The vanishing ways of Bedouin herders maintain a grip on nostalgic Saudi city dwellers.

A fallen locomotive once pulled pilgrims on the Hejaz Railway, built by Ottoman Turks. Tribesmen led by Lawrence of Arabia regularly attacked Hejaz trains during World War I.

own history," says Malak Mohammed Mehmoud Baissa, the mayor of Jeddah's remnant old town. "It isn't taught seriously in schools."

Breakneck economic change. Modernization. From tents to Twitter and glass skyscrapers in barely three generations. Europe must have been this way during the industrial revolution. It is miraculous that Paris survived.

Meanwhile, in the fishing towns along the shore of the Hejaz, the last local fishermen strain to sing sea shanties into my digital recorder. Songs from the age of wooden dhows. Songs of warm Red Sea winds. Of beauties waiting in ports. These Hejazi fishermen, most of whom have hired out their boats to migrant Bangladeshis, have earned their own anthropologists. "It is important," say researchers from the University of Exeter in England, "to capture the last true remnants of the songs of the sea before they become mere pastiches."

WE INCH NORTHWARD toward Jordan. We guzzle a gallon of water a day. We seek out wells of memory.

In Jeddah a female artist honors a lost world, displaying on the old city's walls images of her grandfather sitting with his vanished majlis, a traditional council once common in the homes of Hejaz aristocrats. (The art—titled "Where Is My Majlis?"—is mysteriously removed after a week.)

In Medina a museum director spends seven years of his life constructing a meticulous, 50-foot-square diorama of the holy city's heart, with its mazy alleys and lemon trees. These timeless features were scraped away in the 1980s to make way for high-rise hotels. ("Old residents come here to cry.")

The past is fraught territory in every country. Until barely a generation ago U.S. textbooks rarely acknowledged the complex universe inhabited by Native Americans. Israel points to biblical archaeology to cement its right of existence. Yet in Saudi Arabia this blinkered view is changing.

Riyadh has spent nearly a million dollars on a museum devoted to the Hejaz Railway—the storied Arabian version of the Orient Express—terminating in Medina. Jeddah's antique quarter is also up for review as a UNESCO World Heritage site. (One such global treasure already exists in the Hejaz: Madain Salih, a colossal necropolis of the Nabataean empire.) Most extraordinary of all, an entire Hejazi caravan town of some 800 homes, abandoned and crumbling for 40 years, has been bought by the government for renovation.

WAHHABIS EMPHASIZE THAT ALL THE PAST BEFORE ISLAM IS JAHILIYYA: *A TIME OF IGNORANCE.*

"This is our greatest experiment," says Mutlaq Suleiman Almutlaq, an archaeologist with the Saudi Commission for Tourism and Antiquities, and the curator of the ancient caravansary town of Al Ula. "We are looking back more. This is good."

Almutlaq is an earnest, friendly man. He scrambles ahead of me in his white thobe through the walled ghost town located south of Madain Salih. He vaults broken archways and pokes through covered medieval streets. He shows me courtyards where traders hawked incense, lapis, and silk for eight centuries. Kerosene lanterns manufactured in Germany rust on the floors of the empty homes. The legendary Muslim explorer Ibn Battuta passed through in the 14th century, praising the honesty of Al Ula's populace: Pilgrims stored their luggage here en route to Mecca. Almutlaq takes pride in this fact. He lived and worked in Al Ula as a youth. The site's residents were trucked, en masse, to modern apartments in the 1970s.

"I remember," he says, smiling. And he talks of traveling merchants loading bales of Egyptian textiles. Of farmers stalking in at dusk from

Rabah al Rhafe is true to the Bedouin way. At sundown the herder breaks the Ramadan fast with bread and goat's milk. Husband to three wives and father to 20, Al Rhafe travels like his forebears, moving from well to well, praising Allah for this life.

the fields. Of women talking to each other from windows latticed for modesty.

Twin wells of memory: Almutlaq's glasses, flashing excitedly amid the dim archaeology of his childhood.

WE ARE ALL PILGRIMS in the Hejaz. Wanderers through time. We stop at its wells, or we pass them by. It matters little. Used or not, the wells remain. In their basements shine disks of pale sky—the unblinking eyes of memory.

After six months of walking, I say goodbye to my guides Ali and Awad. I cross the Haql border from Saudi Arabia to Jordan. I carry little. A shoulder bag of notebooks bound with rubber bands. Seven hundred miles of words. Pages crazed with jottings about devastating heat. Inked maps of pilgrim roads. Divinations of Bedouin fire doctors. Bearings for remote wells.

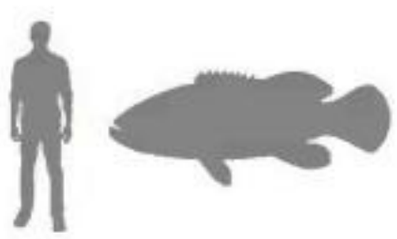
I reach a modern tourist resort. No one pays me any mind. There is the novelty of women driving cars. I watch couples strolling beaches in sarongs. I stop at a mini-mart and buy a bottle of filtered water: a small plastic well, an artifact from the main channel of history. I peer south, beyond the Gulf of Aqaba—toward the Hejaz. A cloaked place. The lips of its ancient wells are grooved by ropes turned to dust. Dust long since blown away. I sip my water. It tastes utterly ordinary. □

Big fish

If the goliath grouper loses its legal protection, will the 800-pounder sink or swim?

Goliath groupers emerge from a blizzard of baitfish on a WWII shipwreck off Florida.

By Jennifer S. Holland
Photographs by David Doubilet
and Jennifer Hayes



Off the coast of southwest Florida, a hundred feet below the water's surface, a *whump* rolls through the sea. Another *whump* follows, like the boom of distant fireworks. It's coming from the carcass of a drowned ship. Packed into the cracked-open belly of the wreck are a dozen very big—and very audible—fish.

These are Atlantic goliath groupers. They gather on shipwrecks and reefs to eat and socialize. At up to 800 pounds and nine feet long, they sport jutting jaws and giant palm fronds for fins and are mottled and spotted in earth tones. They announce their presence to encroaching creatures by squeezing their swim bladders, the air sacs that help keep them afloat. *Whump. Whump. WHUMP!*

Nowadays when it comes to goliaths, people are the noisy ones. Atlantic goliaths used to be numerous and widespread, inhabiting the waters of the southern United States, the Caribbean, and Brazil by the tens of thousands. But after years of being speared and hooked by the boatload, their numbers dwindled to an unknown low, perhaps below a thousand. The Florida population is now rebounding, and fishermen, biologists, and local officials are raising their voices over whether the animals have recovered enough to shed their legal protection from people wielding spearguns and fishing lines.

Chris Koenig of Florida State University has been catching goliaths for decades, but not to bring them home as fillets or trophies. With the help of some strong assistants, he hooks goliaths and wrestles them on board a small boat to measure them, remove a cartilaginous fin ray for DNA and age tests, sample the stomach contents for diet studies, and check reproductive organs for signs of spawning. Each fish gets a tag beneath its skin before the scientists slide the animal back into the sea. Tracking his catch-and-release fish, Koenig has been able to pile up information on where and when they show up and how healthy each one is. He and his wife and colleague, Felicia Coleman, who helps manage the slew of data, hope to get a handle on the current status of the species, *Epinephelus itajara.*

The goliath's own behavior contributed to its population drop. "Ordinarily these fish don't move a whit; they are glued to the reef," where food and shelter are plentiful, Koenig says.

That makes them easy targets. "We used to shoot goliaths all the time," says 86-year-old Frank Hammett, who spent much of his 20s with speargun in hand. "In Palm Beach you could see them sitting on the bottom in a hundred feet of water. The reefs were covered with them. There might be a hundred in one spot or a wall

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Jennifer S. Holland's new book, Unlikely Heroes, *will be out this fall. David Doubilet and Jennifer Hayes explored the Gulf of St. Lawrence for the May issue.*

Captain Tony Tarracino and his family pose in 1958 with a day's catch from the Florida Keys. Recreational hauls of goliaths helped push them near extinction.

of them—something you don't forget! I'd shoot one or two, get eight cents a pound for them. Did that for 15 years or more."

For a while the grouper's commercial appeal was regional—in the Florida Keys goliath grouper with black beans and rice was a delicacy—but when other fish stocks waned in the early 1980s, goliaths landed on menus everywhere. They were also a recreational favorite; sportsmen loved overpowering the giants. Many thousands died as trophies. Long-lived and slow to mature, the species simply couldn't keep up with the slaughter. It teetered on the edge of extinction.

But it didn't fall. In 1990 the goliath, identified as endangered, received legal protection in the southeastern U.S. The fish have been slowly rebuilding their population ever since—and attracting scuba divers, who delight in swimming with the immense but nonthreatening fish. The biggest recovery—perhaps as many as thousands of fish—has been off southwest Florida where the mangrove forests, the home of the juveniles, remain thick.

As often happens in the world of conservation, there are two distinct sides on the issue of goliaths. Still considered critically endangered in much of their range, goliaths in Florida remain legally off-limits. "The political pendulum has swung so far toward protection that you can't even touch or look at one," says Key West City Commissioner Tony Yaniz. "You're better off getting caught with bales of marijuana than with one of these fish."

Yet many fishermen insist the animal has returned in droves. And they complain that the big fish interfere with business. "We have goliaths taking legal grouper and snapper right off our

MONROE COUNTY PUBLIC LIBRARY, FLORIDA

This ten-inch-long juvenile goliath in the Florida Keys may spend five years among mangroves, relatively safe from predators, before venturing out to the reefs. The species' survival depends on mangrove forests, which are contending with coastal development.

Struggling for survival

After overfishing nearly annihilated them in the 1970s and '80s, Atlantic goliath groupers are slowly recovering, especially juvenile populations in the mangrove forests near Ten Thousand Islands, according to a study of tagged fish. As adults, goliaths stick close to familiar ocean spots, except for an annual trip to distant spawning sites.

COMMERCIAL CATCH (FLORIDA)

1950 **97,500 lbs.**
1977 **126,283**
1989 **148,646**

In 1990 fishing for grouper was banned.

1991 **0**

ATLANTIC GOLIATH GROUPER RANGE

RYAN MORRIS, NGM STAFF
SOURCES: CHRISTOPHER C. KOENIG AND KELLY KINGON, FLORIDA STATE UNIVERSITY

lines, over and over," says commercial fisherman and guide Jim Thomas. "Lobsters too. It's such a waste." He is one of many who want to be able to fish for goliaths—even just a few annually—to thin out the alleged thieves. It doesn't have to be a one-sided benefit, Yaniz adds. Why not have the fishermen contribute to answering the conservation questions by providing data on numbers and sizes of fish? "They're the ones out there every day, with eyes on the water. They can really help us figure out where the species stands."

Conservationists think the fishing community is off base. Koenig and other non-fishermen with "eyes on the water" strongly dispute the claim that groupers are sucking up fishermen's haul. Studies have repeatedly shown that the lumbering goliaths feed almost exclusively on small, slow targets (crabs, not lobsters, make up more than half their diet).

Koenig says that giving permission to fish for goliaths in Florida where numbers are up could hamper overall recovery. These fish mostly stick close to the same shallow reefs, rocky ledges, and wrecked ships. "As homebodies," he explains, "goliaths are already reluctant to relocate." So if you thin out the most crowded areas, the remaining goliaths have even less reason to recolonize places where the species has died out. And that means recovery won't be as widespread as it could be.

Koenig and Coleman have found that the only time goliaths really move far is for spawning. "When it comes time to mate, they will travel great distances to get to spawning sites, nearly 300 miles in some cases," says Koenig. "They might cover 25 miles a day in a beeline." Fish from far and wide, maybe from the entire Atlantic seaboard, congregate offshore near

Goliaths hover in a strong current above the Zion Train artificial reef near Jupiter, Florida. The fish gather on wrecks and reefs by the tens or even hundreds in preparation for spawning. This behavior, which peaks during the new moons of August and September, makes them easy to catch.

shipwrecks and reefs, sidling together in bullet-shaped masses, bumping and nuzzling and sounding off in the dark of night as they send up sperm and eggs to build the next generation.

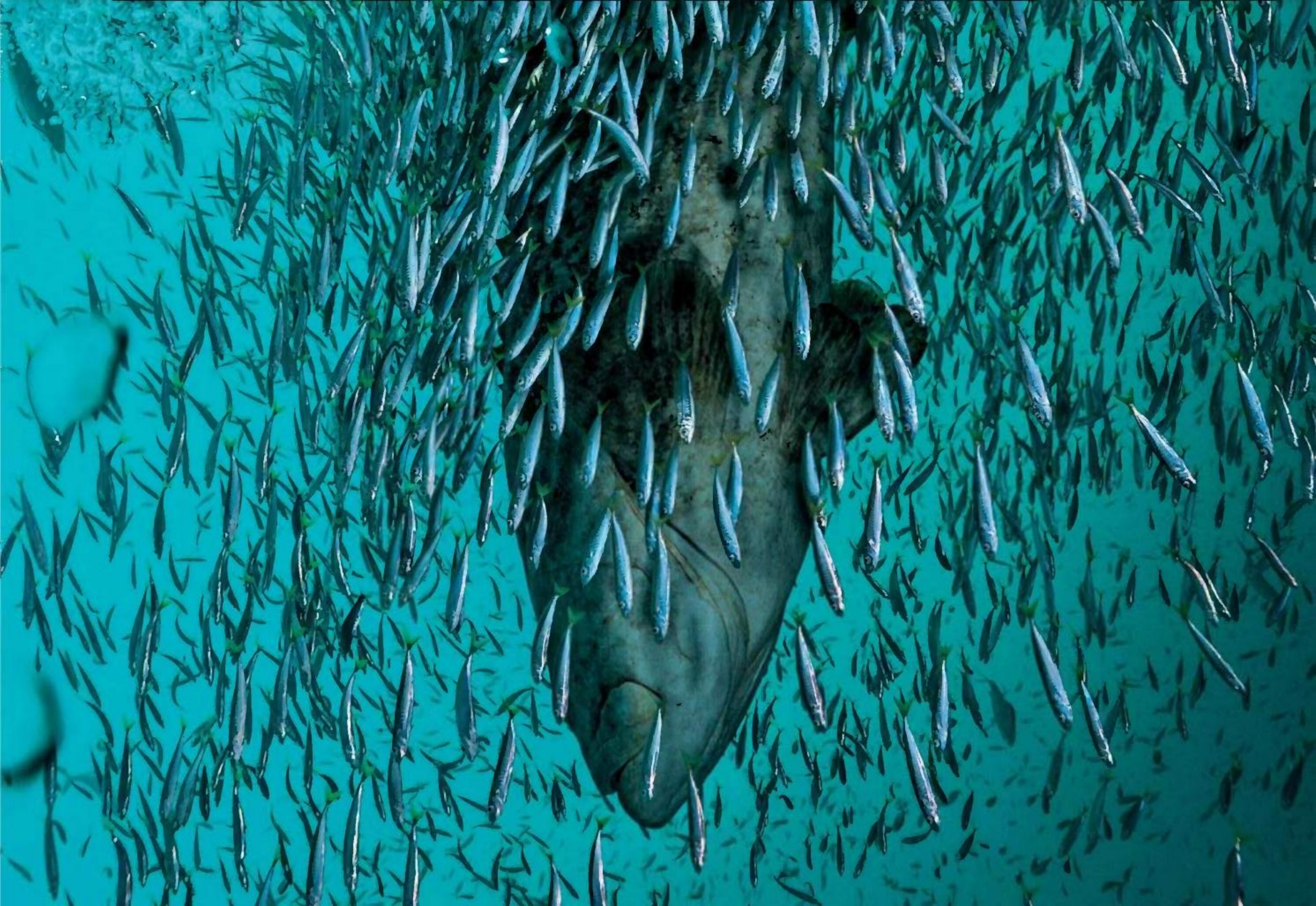
However successful their mating, a return to historic high numbers may be just a dream for the big fish. Koenig says exposure to mercury is having "an insidious toxic impact" on the animals. "The adults have actual pathologies—lesions in the liver—from the levels of mercury," he says. Not only might that be partly to blame for the fish's decline, but also it means we shouldn't be eating these things. "If you were to catch anything over about four feet long," says Don DeMaria, a former commercial fisherman who assists with conservation efforts, "you would have to throw it back anyway." The mercury, he says, "makes it inedible."

The future of goliaths is also tied up in those mangrove nurseries, where the fish live around the trees' tangled roots until they are about five years old. Coastal development, agriculture, and pollutants threaten these shallow-water habitats. The current trajectory suggests 20 percent losses of remaining U.S. mangroves in the next 50 years—devastating for young, developing goliaths, which are already reeling from unusually cold winters that took out thousands of the fish from their juvenile habitat throughout South Florida.

Ultimately fishermen and biologists and even government officials want the same thing: a grouper population big and vigorous enough to keep divers coming and to weather a few hooks in the water without collapsing. While the debate rattles on, the goliaths in question continue booming beneath the waves.

The big fish, too, just want to be heard. □

Gregarious and physical, goliaths are rarely seen solo and seem to socialize equally across the sexes. Recently scientists discovered that some are "protogynous hermaphrodites," meaning they are born females but transform into males. It isn't yet clear why they evolved this way.



Baitfish cloak a female goliath as she prepares to spawn with a nearby male. When ready, she will release thousands of eggs near the surface; the male will follow with a cloud of sperm. And the baitfish will feast on as many eggs as they can before the current clears the scene.

EMPIRE OF ROCK

Explorers use a laser scanner to see China's giant caverns as never before.

Climber Emily Harrington takes the hard way up southern China's Moon Hill, an arch from the remains of a collapsed cave. Sightseers have an easier option: a paved walkway to a viewpoint beneath the arch, then a dirt path to the top.

The photographer's lights illuminate the green-hued Getu He river in the Miao Room—considered the world's second largest cave chamber by area. Opposite: Cedar Wright, Matt Segal, and Harrington ascend a limestone spire in Enshi canyon

The Stone Forest is a labyrinthine world of eroded and dissolved limestone near the southern Chinese city of Kunming. Early visitors gave the formations names like “rhinoceros admiring the moon” and “stone singing praises of plums.”

BY McKENZIE FUNK PHOTOGRAPHS BY CARSTEN PETER

Crouched on the floor in the mud in one of the biggest cave chambers in China, one of the biggest in the world, we can hear nothing but our breathing and the drip, drip of distant water. We can see nothing but a void. Then we turn to the screen of a laptop connected to a laser scanner, and the Hong Meigui Chamber reveals itself. We float up to its roof, which forms a cathedral arch 950 feet above the cracked mud where we are crouched to avoid the scanner's beam. We hover over a lake. We touch down on a beach on the far side.

"It's like Google Earth," I say.

"It's like *The Matrix*," says Daniela Pani, the Sardinian geoscientist operating the laptop.

The digital version of the cave is more real than real life. Real caves are dark. Extremely dark. In a big chamber, even with modern LED headlamps many times brighter than the old carbide ones, you can see 150 or so feet ahead or above, and not much more. Mist or emptiness overwhelms even the brightest beam. It's natural to want to see more.

Wanting to see more is what drew Andy Eavis to southern China more than 30 years ago. Here in the still cloistered country was the planet's greatest concentration of the otherworldly

Yangshuo was a sleepy village two decades ago, when foreign climbers and cavers began frequenting nearby formations. Today domestic tourists vastly outnumber foreign visitors.

topography known as karst: sinkholes, stone towers, forested spires, and disappearing rivers that form over centuries as rainwater dissolves a soluble bedrock, usually limestone. And hidden inside and underneath this green mountainscape—the same iconic scenery found in traditional Chinese paintings—was the planet's greatest concentration of undocumented caves.

That's also why Eavis has come yet again to China, this time toting well-worn caving bags overloaded with new laptops, batteries, and a rented 3-D laser scanner worth more than $100,000. In a cave, technology can capture what the human eye cannot. His plan is to spend a month in at least three of the biggest chambers in the world, turn on the scanner—and measure them precisely for the first time.

A white-haired plug of an Englishman in his late 60s, who made a fortune in plastics manufacturing, Eavis is often said to have discovered more miles of territory than anyone alive. Expeditions he has led have documented 330 miles of new cave passages, and counting. "That's why I cave," he says. "To explore. In caving you can be the first. If there were countries left to explore, continents to explore, I would."

Eavis, now the chairman of the British Caving Association, first came to China in 1982. The visit to its karst capital, Guilin, in the humid far southeast of the country, was a quick stop on his way back home from an expedition in Indonesia. The peak-ringed city and surrounding Guangxi region were then a different place: bicycles but few cars, peasants in blue work suits, escorts for foreigners. Eavis and his partner skipped much of the tourist program to meet with officials at the Institute of Karst Geology, the beginning of a relationship that would bring British and Chinese cavers into the limestone for the next three decades. The pace of discoveries would be nearly as rapid and stunning as China's own transformation during those same years.

Eavis is in Guilin this time with a team of ten international cavers. When we arrive, we are met by a buzz of taxis and scooters in a city swollen to roughly a million people. The new China—freeways, luxury supermalls, peaks turned into quarries to feed the boom—is astonishing, especially to two team members. Richard Walters and Peter Smart were with Eavis in Guilin in 1985 and '86, the first of two dozen expeditions that would make up the pioneering China Caves Project. Neither has been back until now.

Walters, a telecom entrepreneur who has been known since childhood as Roo, will help operate the scanner along with Pani, who in past work discovered sunken WWII ships in the Mediterranean and helped support astronaut training in the caves of her native Sardinia. Smart, a noted karst scientist who retired from the University of Bristol in 2009, has a professorial beard and

perpetually crooked glasses. He had to be persuaded to use a modern descender, a device to control his slide down a caving rope—his old one was just fine, thank you. But he is excited by the innovation that is laser scanning, also known as lidar, because otherwise "caving is through a glass darkly." For all of China's change, we find that as we continue west from Guilin toward the biggest cave chambers, Smart's expert description of the landscape still fits. "From above," he says, "it looks like an egg box."

BY AREA, HONG MEIGUI CHAMBER, the first we plan to scan, is thought to be roughly the size of nine football fields. It is number eight on a 2012 list that cavers have been passing around of the world's largest known cave rooms, behind contenders in Malaysia, Spain, Oman, Belize, and elsewhere in China—but where it ranks by volume is a question we hope to start answering in 3-D. Our base for this early part of the expedition is not a subterranean camp but an aging, industrial-size hotel in the town of Leye, which had 5,000 people when first visited by the China Caves Project. Now it has many times that, and more than 160,000 tourists a year come to see the nearby Dashiwei Tiankeng, a 2,000-foot-wide, 2,000-foot-deep sinkhole first known to Karst Institute scientists in 1998 and explored by the China Caves Project two years later. A

Wright balances atop a spire in the Stone Forest. Deposited in a shallow sea 270 million years ago, the limestone here was eroded by heavy tropical rains.

photo of Eavis is displayed in the local museum.

To reach Hong Meigui each day, we drive to a parking lot not far from town, where we change into coveralls and don harnesses and helmets and headlamps, then walk for a minute or two to an unremarkable-looking opening in the forested mountainside. Past a concrete cistern farmers use to collect water dripping from an overhanging roof, the cave swiftly becomes colder and steeper and darker. Soon enough, we are in another world.

Two short rappels—maybe 15 feet and 50 feet—have been rigged by the group's two ablest cavers, Tim Allen and Mark Richardson. Otherwise the approach is on foot. For much of an hour on my first descent, I follow Tim's wife, Jane Allen, another expert caver, down a staircase of pools shimmering in our headlamps and into a tubelike passage where the surface looks like—and sometimes surely is—a river of mud.

The sensation when we enter Hong Meigui Chamber itself is both dizzying and familiar. I can see that it is big simply because I can't see much at all; no longer does my light bounce off a ceiling or walls. Particles float in the air, for not even the wind can reach here. A boulder the size of a dump truck has fallen to the floor from someplace dramatically high above, its crater ringed by a shock wave of mud; the team names it "the meteorite." Somewhere far on the other side of the room—exactly how far is hard to gauge—the beam of someone's lamp bobs along. Only when I begin scrambling up a rubble slope does the experience seem familiar. The slope is so big, the progress so gradual, the terrain so rough, it feels like mountain climbing on a starless night.

GIVEN THE IRREGULAR SHAPES OF CAVES, it can be hard to decide where each room ends, where to draw the boundary lines. What constitutes a cave chamber, and what a mere passage? This semantic question will be constantly argued over by expedition members, for one of the eventual goals of 3-D scanning—a ranking of the world's largest chambers by volume—is impossible if cave explorers can't agree on a definition.

The largest known is Sarawak Chamber in Malaysia, which Eavis and two others discovered in 1980 and helped scan in 2011. Its estimated volume is 338 million cubic feet—more than three times the size of the new Dallas Cowboys stadium in Texas. My layman's answer to the definition question is that we never argue over whether something is a full-blown hall or a hallway; you know it when you see it. In the case of caves, you can't entirely see it. But you know it: There is the unmistakable impression of

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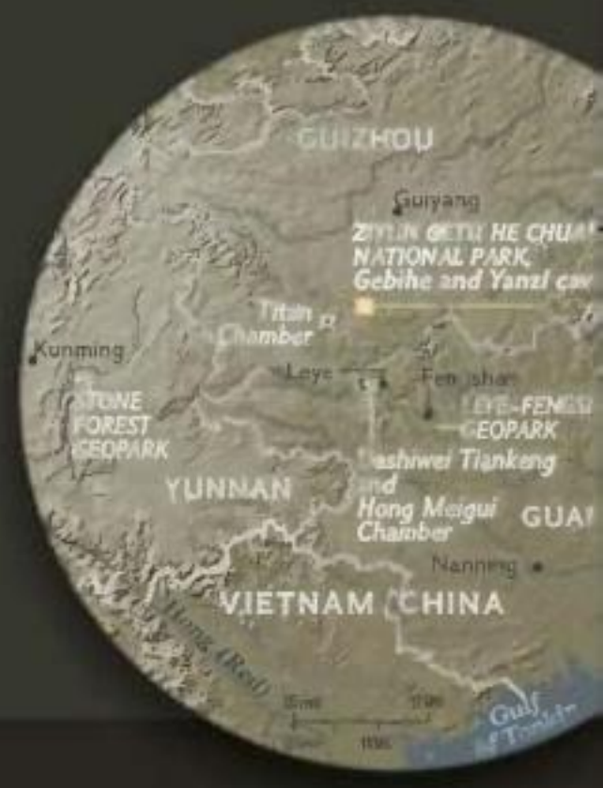
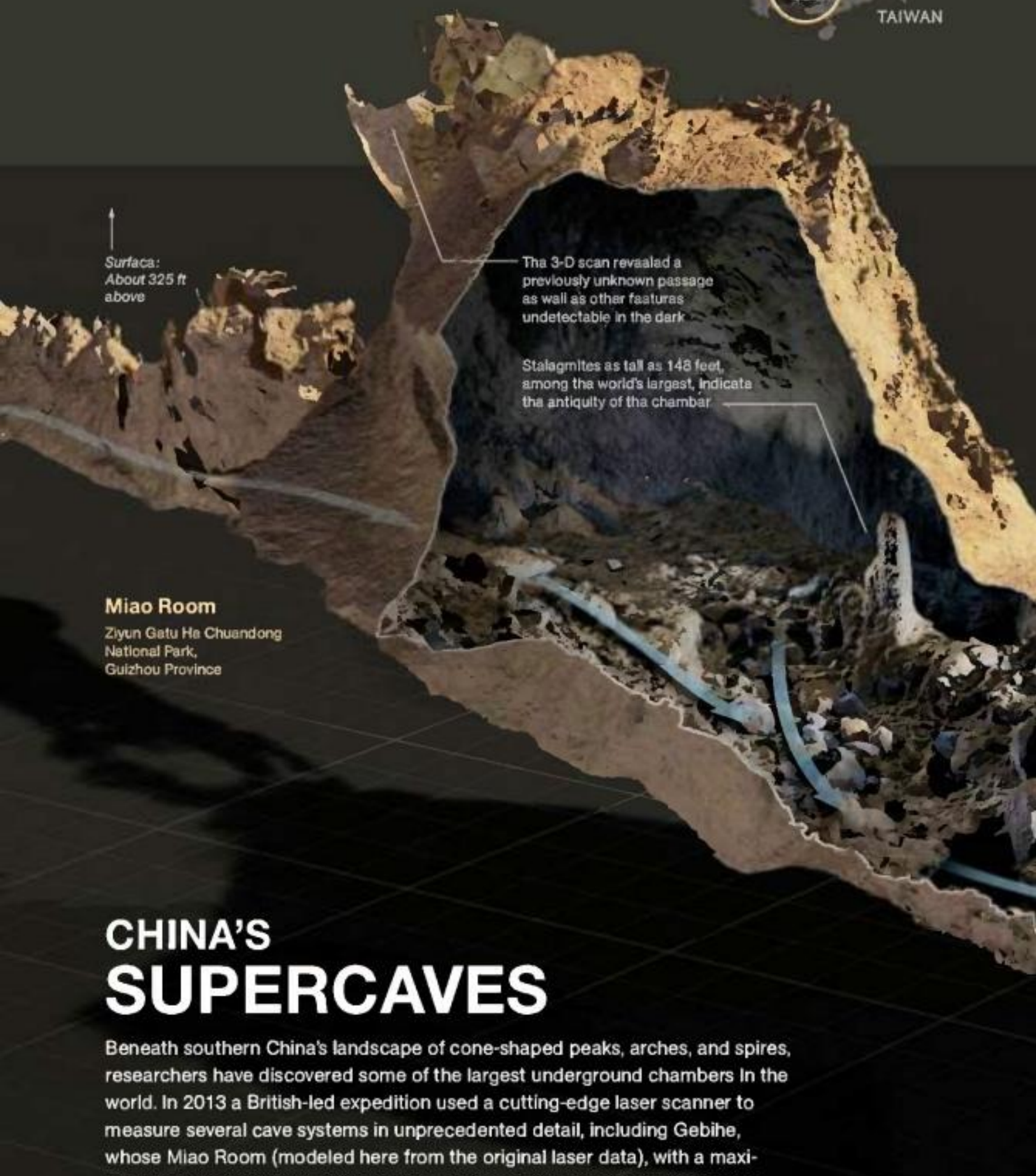
McKenzie Funk's new book is Windfall: The Booming Business of Global Warming. *Carsten Peter's photos of Vietnam's caves appeared in our January 2011 issue.*

CHINA'S UNDERGROUND KINGDOM
Southern China holds the world's largest concentration of the eroded topography called karst. For more than 600 million years, this region was covered by a sea and accumulated miles-thick layers of sediments, including limestone. Uplift and erosion of the geological formation created today's massive caverns.

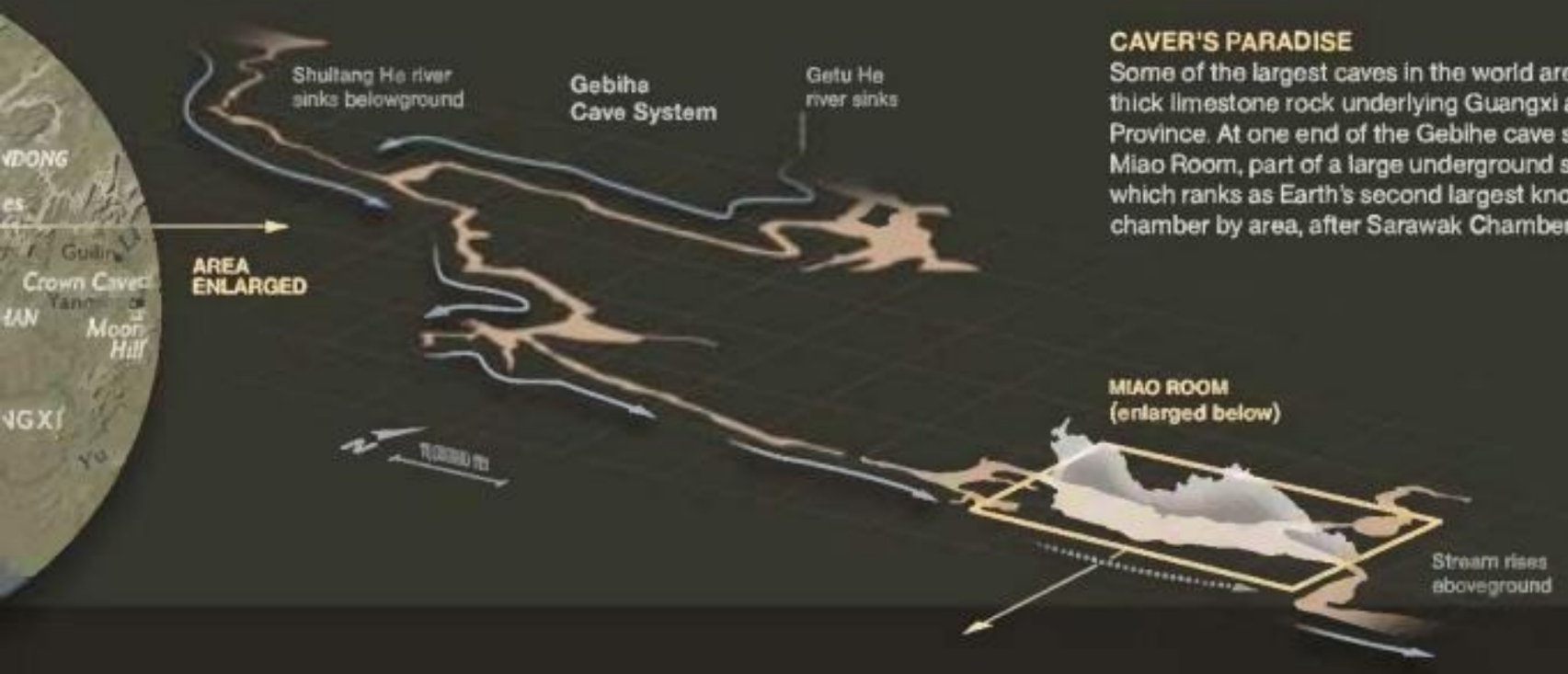




Miao Room
Ziyun Gatu He Chuandong National Park, Guizhou Province

CHINA'S SUPERCAVES

Beneath southern China's landscape of cone-shaped peaks, arches, and spires, researchers have discovered some of the largest underground chambers in the world. In 2013 a British-led expedition used a cutting-edge laser scanner to measure several cave systems in unprecedented detail, including Gebihe, whose Miao Room (modeled here from the original laser data), with a maximum height of 627 feet, ranks as the world's second largest known chamber.



CAVER'S PARADISE

Some of the largest caves in the world are found in the thick limestone rock underlying Guangxi and Guizhou Province. At one end of the Gebihe cave system is the Miao Room, part of a large underground stream course, which ranks as Earth's second largest known cave chamber by area, after Sarawak Chamber in Malaysia.

JUAN VELASCO, MARTIN GAMACHE, AND LAUREN JAMES, NGM STAFF. ART: STEFAN FICHTEL, IXTRACT GMBH. SCAN DATA PREPARATION: JOE BEECHING, 3D LASER MAPPING

SOURCES: ANDY EAVIS, TIM ALLEN, RICHARD WALTERS, PETER SMART, DANIELA PAIC, JANE ALLEN, AND MARK RICHARDSON, CHINA CAVES PROJECT; ZHANG HAI, INSTITUTE OF KARST GEOLOGY, GUILIN, CHINA

Explore inside the Miao Room on our digital editions.

Two massive domes are connected by a 2,795-foot-long passage. Whether Miao is a single chamber, two chambers, or a giant passage has not yet been resolved.

Some data gaps, or "shadows," appear in areas hidden to the laser scanner.

The 3-D laser scan revealed debris from cave collapses. Researchers can study this debris to better understand how the chamber grows.

CHAMBERS SCANNED

1,270,141 square feet
(22 football fields)

Titan
Fifth

581,251
sq ft

Hong Meigui
Eighth

516,667
sq ft

Boeing 747
(shown for scale)

To access the cave, team members used boats to cross a lake created by a dam at the cave entrance.

Members of a British-led expedition pause at a subterranean lake on the way to Titan Chamber in southern Guizhou Province, where it rains more than 50 inches a year. The lake appears and disappears as the rains come and go.

empty space. None of the cavers find this answer satisfying in the least.

When I catch up with the scanning team, they are in the cracked mud near the meteorite, not far from the edge of the lake and the sheer face of a limestone wall that leads to the hidden roof of the cave. This is one of 17 scanning stations in Hong Meigui—so many because a laser scanner can see no better around a corner or a boulder than a human can. The scanner emits laser pulses and measures how long it takes for them to be reflected back. Distances are easily determined based on the speed of light. Our model is a Riegl VZ-400, used in architecture, engineering, and mining and now for the first time in caving. It's a metal cylinder about the size of a human head and weighs 21 pounds, not including its two nine-pound batteries or the tripod or laptop and cables. When running, it sits at about eye level, spinning 360 degrees and taking up to 122,000 measurements per second of everything within a maximum 2,000-foot radius.

To set up the scanning station, Walters uses a pocket level to ensure that the tripod is true, orients the scanner with a compass, then pulls a

Society Grant The British-led cave expedition and the rock climbing expedition by Cedar Wright, Emily Harrington, and Matt Segal were both funded in part by your National Geographic Society membership.

A boatman guides tourists down the Poxin River as it emerges from underground. The river is part of an extensive geopark that also includes Dashiwei Tiankeng, a 2,000-foot-deep collapsed cave.

new 17-inch laptop out of a waterproof case and hands it to Pani, who sits in the muck with the computer on her lap. Eavis stands nearby, shuffling bags out of view and generally trying to hasten the process—the faster this cave is scanned, the more chambers we can visit—to the frequent annoyance of the meticulous Pani. They attach a blue-green Ethernet cable to the laptop and push a button on the laser scanner, and suddenly it comes alive, its head silently revolving as the team seems to hold its collective breath.

Three minutes later the results appear on Pani's laptop. The rendering is in black and white and low resolution. But it is stunning. There, as we crouch in the dark in the mud, staring at the bright screen, Pani flies us through the virtual cave—and I can finally see where I am. It's an out-of-body experience.

AS THE EXPEDITION MOVES ON to two other great chambers, Miao and Titan, we are reminded that Hong Meigui is an oddity in China for reasons beyond its scale. First explored in 2001 by foreign cavers, the chamber did not have a single human footprint until they arrived—perhaps because the two cliffs at its entrance discouraged locals. Many caves in southern China have a human history that dates back to at least the Qin and Han dynasties, two millennia ago. Underground studies during that time were in the pursuit of chi, or life energy, which the karst regions were believed to possess in great abundance. Stalagmites and rimstone pools also provided ingredients for early aphrodisiacs and medicines; cave chambers became places for prayer. Even today farmers use cave entrances to store and dry grain.

On our way to Hong Meigui, we had stopped in Fengshan, eight hours west of Guilin and part of the new, 360-square-mile Leye-Fengshan Geopark. Here was a large municipal cave, Chuanlongyan, that enclosed a two-lane road, an open-air museum, and a public amphitheater. When I strolled down the road one afternoon, a young couple had stopped their motorcycle in a far corner of the museum parking lot and were kissing in the darkness. "This is the best use for a cave," admitted the geopark's resident foreign expert, French caver Jean Bottazzi.

Bottazzi, Eavis, and Smart showed rough scans of local caves to a regional official in Fengshan. He immediately wondered if they could tell which sections of a cave were unstable. Eavis, successful at caving in good part because he's successful at navigating officialdom, picked up the utilitarian thread. "Yes, of course," he said. Smart added, "You could rope off any dangerous areas, so tourists keep to a safe path." The karst region's tourism boom—fueled by China's growing middle class and a nostalgia for iconic landscapes—is on everyone's mind.

In Fengshan we also saw families in orange life jackets pushed by boatmen up an aquamarine

Uphill from the giant Miao Room, 21 families from the Miao minority live under the roof of a cave. They first came, elders say, because of the reliable spring. The cave now contains a basketball court and, until recently, had a school.

river, hooting as they floated by stalactites in low-hanging caverns. Ten hours to the north, Ziyun Getu He Chuandong National Park is already attracting rock climbers. When we arrive from Leye and Hong Meigui, workers are drilling a tourist footpath into the tall walls of Yanzi Cave, named for the swallows that nest in those same walls. It leads to a new elevator. In Getu we scan what is considered to be the planet's second largest cave chamber by area, the Miao Room, as big as 22 football fields.

One day I walk with Eavis and Pani to see an entire village housed in a 600-foot-wide cave nearby. Twenty-one families inhabit roofless bamboo homes, and they have a basketball court, a shuttered primary school—and a small but growing stream of visitors. Enough tourists every week, we are told, that officials now pay the cave dwellers to stay put rather than move to modern homes outside it.

Before the drive south from Getu to our final scanning objective, Titan Chamber, American expedition member Michael Warner tries to make sense of what it is we are doing here. Every chamber we visit has been visited before, he notes, if not by cavers then by farmers—so this is not discovery. "Exploration is just documenting something for the first time," Warner decides. "And laser scanning is the best way yet devised to document a cave."

IF THERE IS A PERFECT CAVE for the fledgling art of subterranean laser scanning, Titan is it. At the center of its massive chamber, slopes covered with rubble and pockmarked with pools creep relentlessly up to twin, 50-foot stalagmites that sit on the very peak of an underground mountain. Place the scanner atop the big one on the right, and you can take in almost all of Titan—about 13 acres, an area slightly larger than Hong Meigui—in a single 360-degree sweep. Past the high point there are more stalagmites, a formation that looks uncannily like the head of a crocodile, teeth included, and an underground lake that dries into a bed of cracked mud while we're there.

When all return to the surface, dirt-streaked and weary, a provincial official is waiting. "Is it the biggest chamber in the world?" he asks. A "yes" would change everything for the local economy. But it is not the biggest in the world. Perhaps it is in the top ten. The list by volume is still being made. The official is disappointed. "But it is one of the most beautiful cave chambers I have ever seen," says Eavis.

We think the expedition is done, but Eavis has a surprise for us the day before we fly home: a cruise through the karst down the Li River, Guilin's top tourist attraction, with a stopover at a cave his team was the first to survey in 1985. He did the cruise in 1982, back when there were a few dozen riverboats. Now there can be a couple hundred a day, each of them carrying a hundred tourists, and thousands of people flood Crown Cave.

The Li River is still beautiful, but Crown Cave, after Titan, is jarring. We are herded into the entrance in groups of 20, each following a guide with a microphone and cheap portable speaker who yells to make her voice heard over the cacophony of other guides. Inside, the stalagmites and pools are lit with gaudy green, red, and purple lights. There are paths and handrails and, in some of the chambers, trinket stands. Partway through the cave is a glass elevator. Our guide hurries us to get in line for the underground train, which will take us to the line for the underground boat trip, which will take us past the underground roller coaster and across the bridges over the underground river.

Eavis hangs back, snapping photos of everything. He was once alone in Crown Cave, mapping it, an explorer discovering hidden passages. Now this. We start jogging up the steps of the path to catch up with our group. "Is this disorienting?" I ask him. "Nah," he says, and he keeps jogging. The tourists are now pulling out cameras of their own, documenting every last corner of Crown Cave that's visible in the artificial light—an exploration of a sort. To Eavis it's the most natural thing in the world. □

For more on the ups and downs of climbers Wright, Harrington, and Segal in China, visit *ngadventure.com.*

Segal and Wright descend from the Great Arch in Ziyun Getu He Chuandong National Park at sunset. A new glass elevator delivers visitors to the foot of the arch. “China just has a different approach to things,” Wright said.

NG CONNECT

Every month this page features our staff picks of National Geographic Society products and events. For more go to *nglive.org*.

NATIONAL GEOGRAPHIC ON TV

The '90s: The Last Great Decade?

The 1990s spawned the Internet, grunge music, and the Hubble telescope. In the United States women were rising in politics, the economy was booming, and the late Kurt Cobain (left, with wife Courtney Love) and his band Nirvana were changing the music scene. Relive those prosperous years this month on the National Geographic Channel.

INITIATIVE

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CHANNEL

KINGDOM OF THE APES Legendary primatologist Jane Goodall (left) spent decades studying the chimpanzees of Gombe Stream National Park in Tanzania. In honor of her work—and her 80th birthday this year—the National Geographic Channel returns to Gombe to find out more about these apes and the stories they have to tell.

TRIP

GALÁPAGOS The green sea turtle (right) is one of many remarkable creatures you'll meet on our naturalist-led voyages to the Galápagos. Book at *ngexpeditions.com/galapagos*.

EXHIBIT

BIRDS OF PARADISE Photographer Tim Laman and ornithologist Edwin Scholes spent eight years documenting all 39 bird of paradise species. Immerse yourself in this brightly colored, elaborately choreographed avian world at Philadelphia's Academy of Natural Sciences. See *ansp.org* for details.

Book of the Month

National Geographic Kids Almanac 2015

Packed with more content than ever, our newest almanac for kids is bursting with amazing photos, fun facts, cool inventions, and more. The 2015 edition features special sections on topics from cute animals to continents, as well as a chapter dedicated to jokes, games, and comics. Look for it wherever books are sold ($14.99).

PHOTOS (FROM TOP): DORA HANDEL, CORBIS; STUART CLARKE; MICHAEL S. NOLAN

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Time Sensitive

Intrigued by a forest of dead date palms, their trunks bent like ancient columns in the water-starved oasis of Yanbu an Nakhl, photographer John Stanmeyer reached into a pocket for his iPhone. He had an idea.

On assignment in the Hejaz, in western Saudi Arabia, Stanmeyer often felt caught in a time warp. "It was as if I had one foot in the present, and the other had stepped back a hundred years."

To capture that sensation, Stanmeyer took photographs of the palms with an app called Hipstamatic; it uses software in this case to mimic the look of faded prints from a film camera. For the next month, in addition to his regular photography, he kept at his Hipstamatic experiments. The vintage-style images caught the feel, he thought, of traveling in a land uncertain of its modernity. His editors agreed. Four of the images appear in the Out of Eden Walk feature this month. *—Tom O'Neill*

Photographer
John Stanmeyer

PHOTOS: JOHN STANMEYER (PALMS); SAMI ALALUL

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FOUND

Water Working Colored lights and dancing spray have put on a show for Chicagoans since 1927, when the Clarence F. Buckingham Memorial Fountain was dedicated in the city's Grant Park. When nights are warm enough, up to 15,000 gallons of water a minute still leap from the tiers of the fountain's 1.5-million-gallon basin. "A major display is given three evenings a week for a period of one hour during the summer months," noted the caption for this photo—its color courtesy of the then new Finlay process—in the May 1931 *Geographic*. The fountain's operation originally depended on two engineers who each worked 12-hour daily shifts. Computers took over in 1980. *—Margaret G. Zackowitz*

Get Lost in Found. Go to **NatGeoFound.tumblr.com.**

PHOTO: CLIFTON ADAMS, NATIONAL GEOGRAPHIC CREATIVE

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Hawksbill Turtle *(Eretmochelys imbricata)*
Size: Body length, up to 114 cm (44.9 inches); carapace length, 63 - 94 cm (24.8 - 37 inches) **Weight:** 40 - 80 kg (88 - 176 lbs) **Habitat:** Tropical oceans around the world; females prefer to nest within maritime forest fringing sandy beaches **Surviving number:** Estimated at 10,000 in 2005

Photographed by David Fleetham

WILDLIFE AS CANON SEES IT

World of water. When foraging, the hawksbill turtle spends 96 percent or more of its time underwater, surfacing only to breathe. It usually returns to the same sandy beach to nest, migrating as far as 280 miles to get there. Females generally lay five clutches of eggs, but do so only every two to three years. The sex of their young is determined by temperature; as climate change makes nests warmer, the result is more females. Dry land is a dangerous place for the turtle, which faces hunting for meat and the tortoiseshell trade, egg collection and habitat loss.

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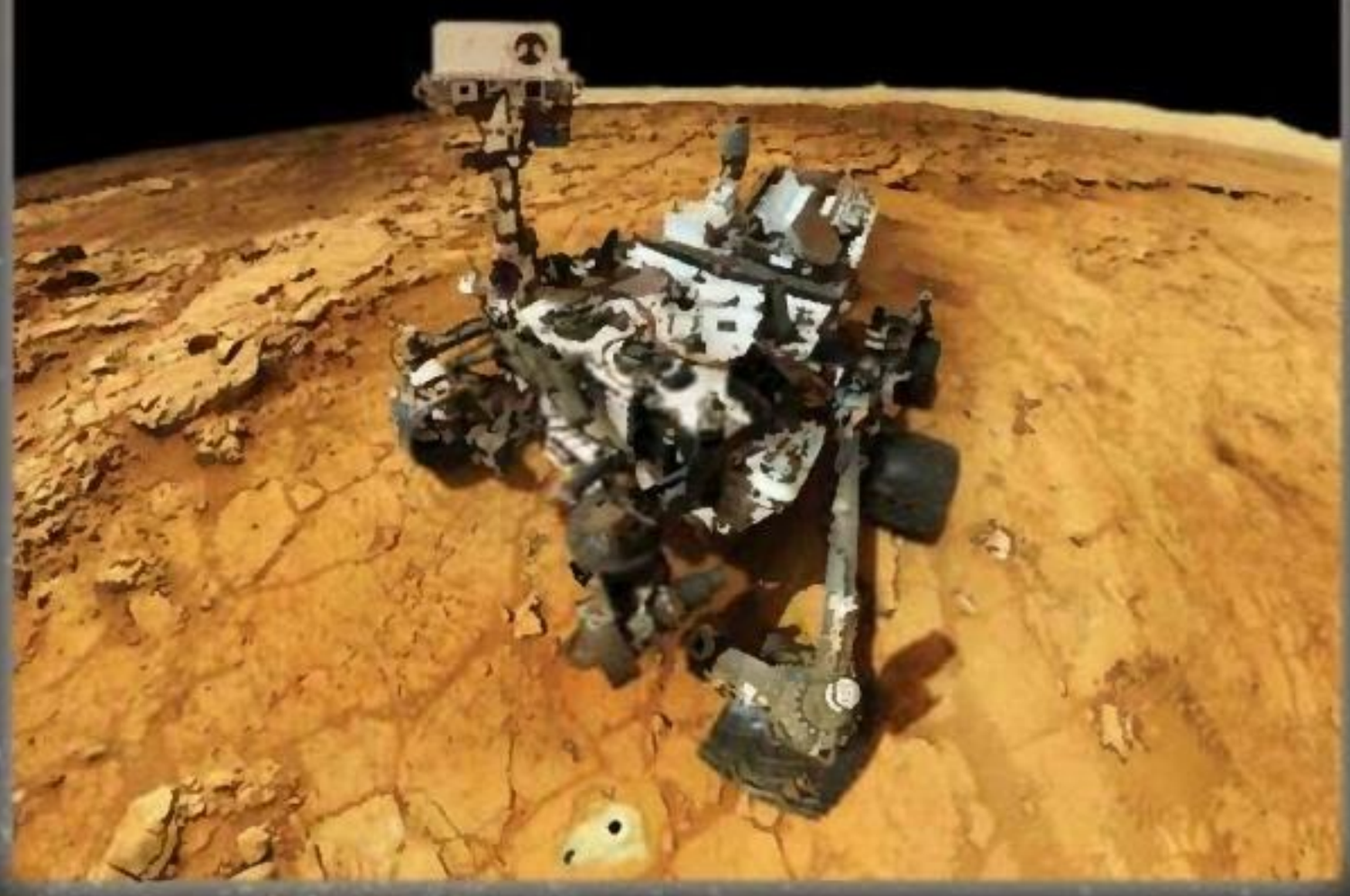

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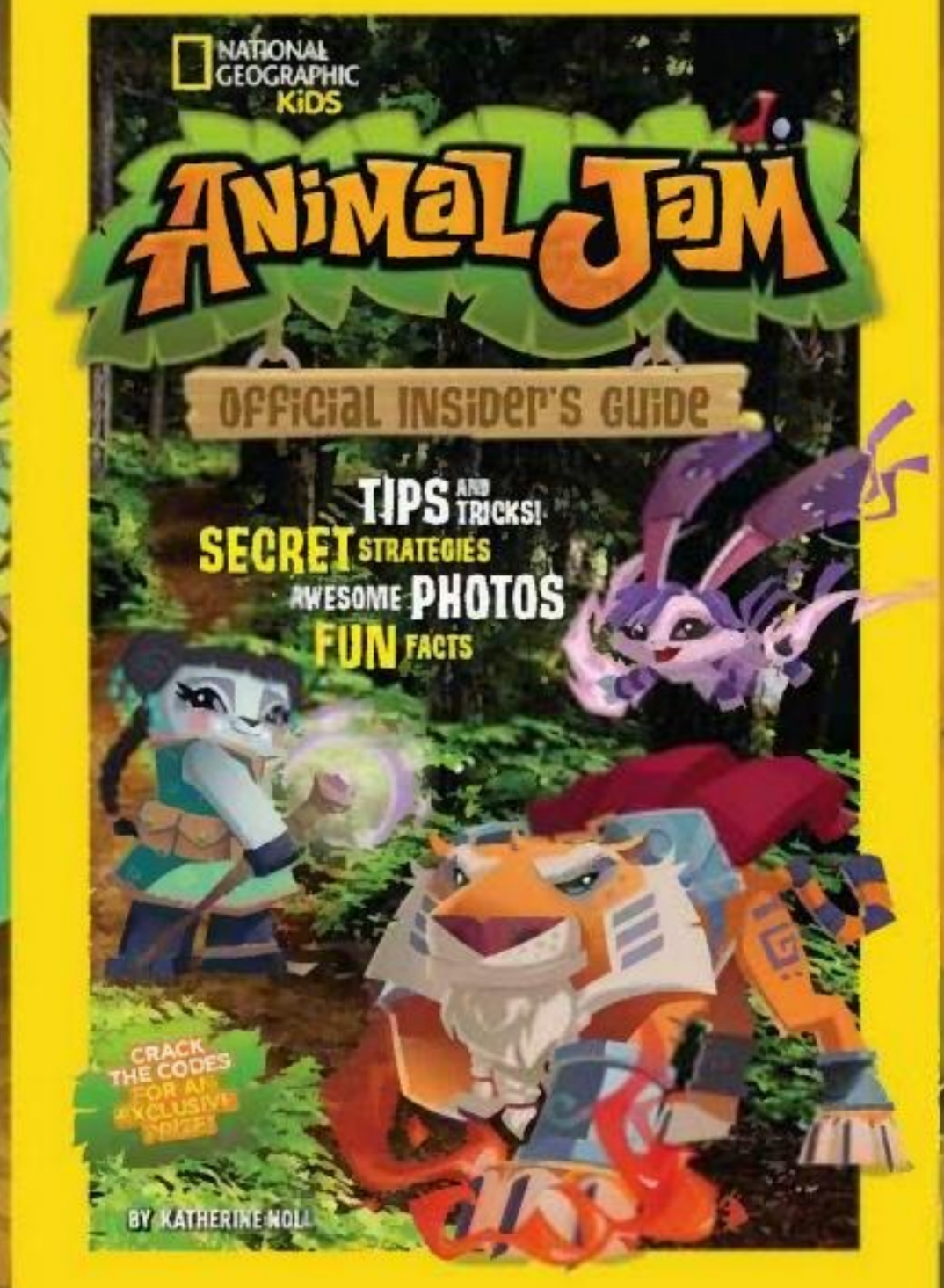

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